INTRODUCTORY CHEMISTRY

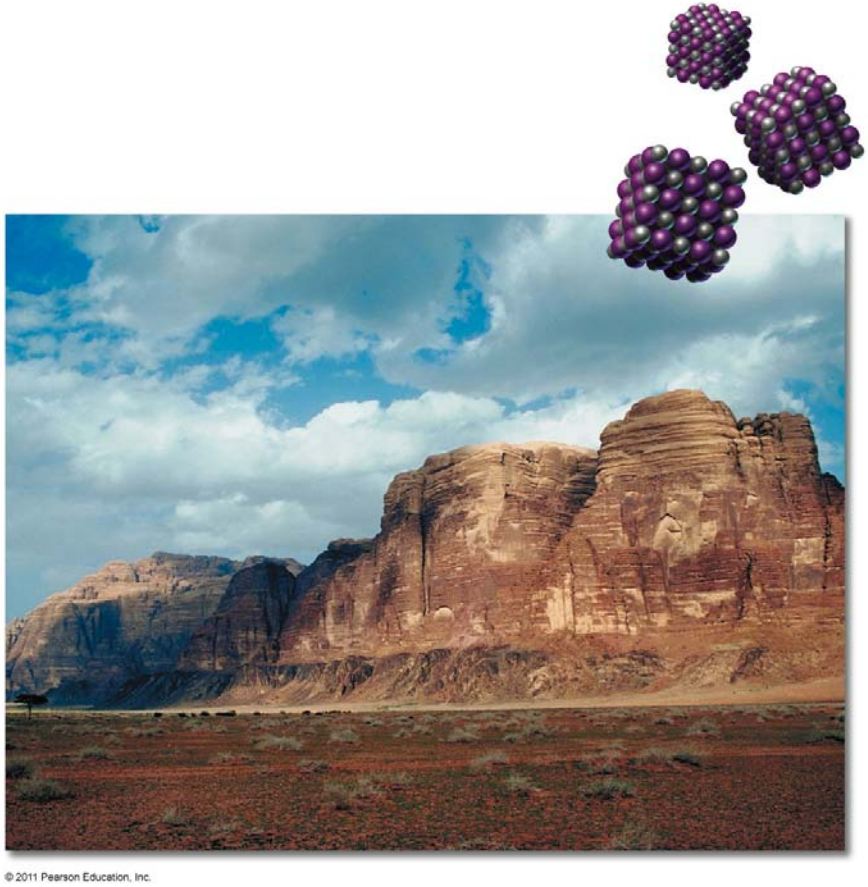
Concepts and Critical Thinking

Sixth Edition by Charles H. Corwin

Chapter 7

Language of Chemistry

by Christopher Hamaker



IUPAC

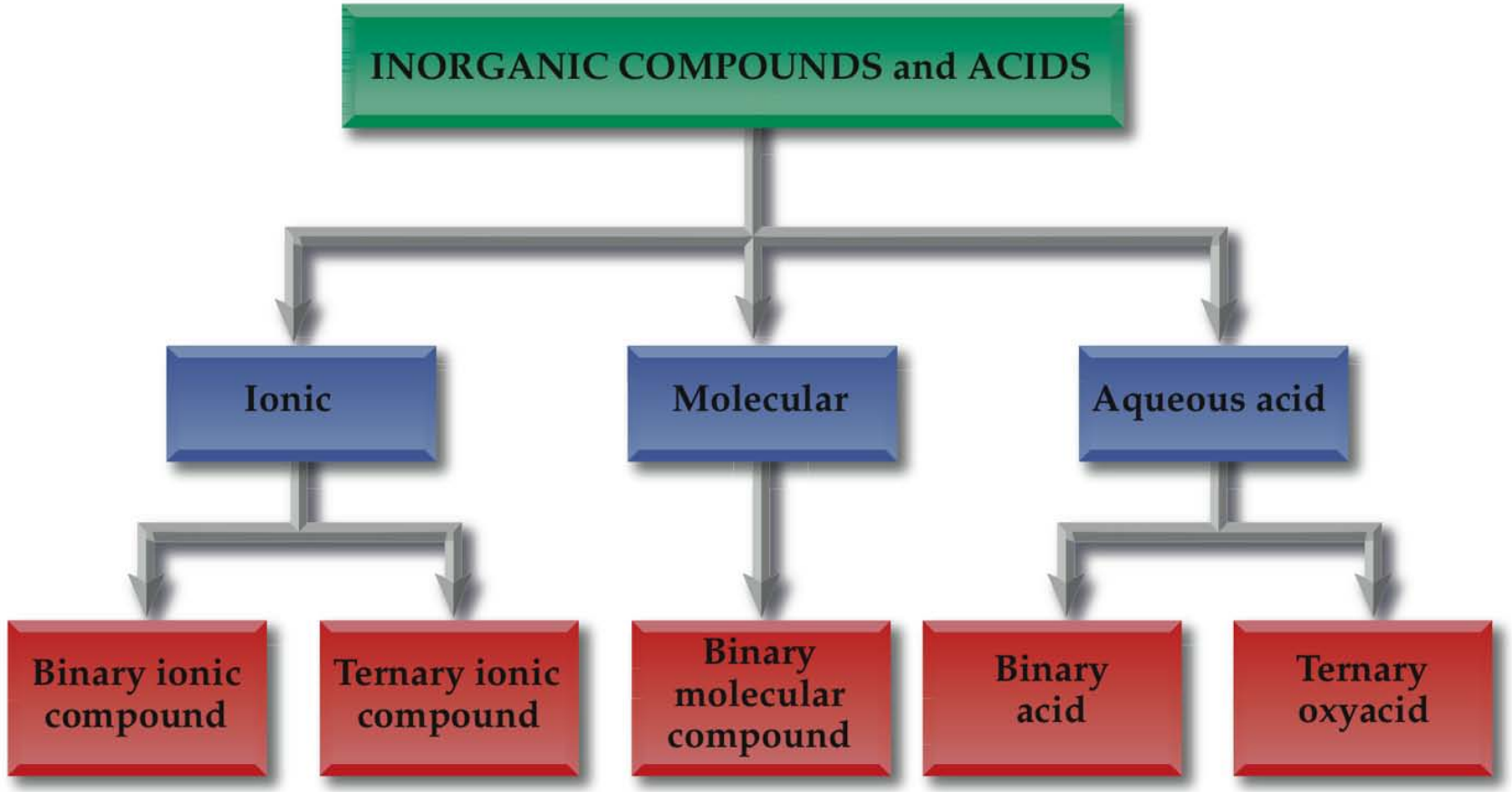
- The **I**nternational **U**nion of **P**ure and **A**pplied **C**hemistry, IUPAC, has set rules for naming compounds.
- IUPAC set the rules for the naming and classification of inorganic compounds in 1940.
- These rules, referred to as ***IUPAC nomenclature***, are still in use today.

Classification of Compounds

- Most inorganic compounds do not contain the element carbon.
- The exceptions are carbon dioxide, CO_2, and carbonates, which contain the ion CO_3^{2-}.
- There are five common classes of inorganic compounds:
  1. Binary ionic
  2. Ternary ionic
  3. Binary molecular
  4. Binary acid
  5. Ternary oxyacid

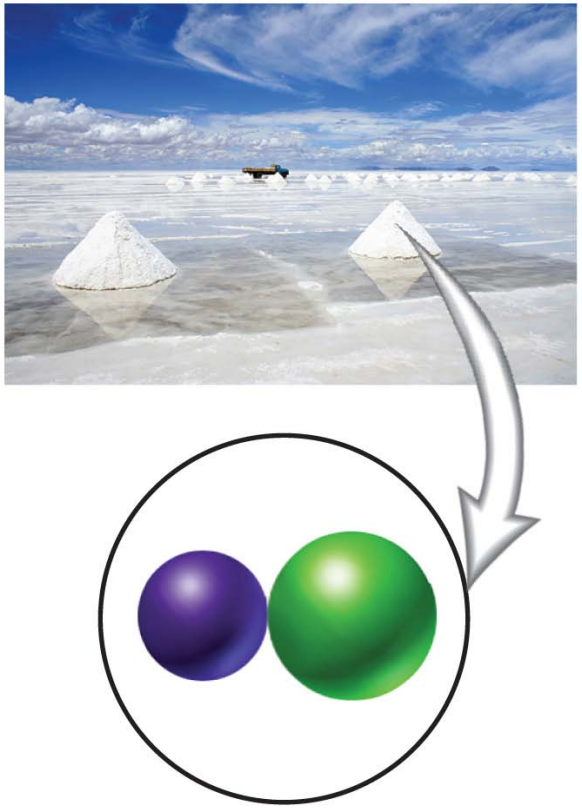
Classification of Compounds, Continued

- Below is a flow chart for the classification of inorganic compounds.



Ionic Compounds

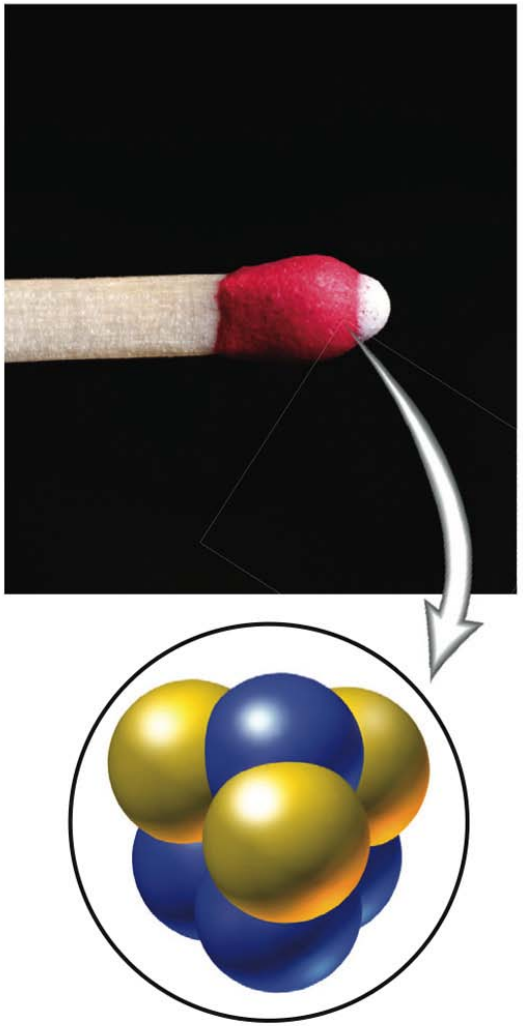
- ***Binary ionic compounds*** contain two elements: one metal and one nonmetal.
  - NaCl and $AlCl_3$ are binary ionic compounds.
- ***Ternary ionic compounds*** contain three elements, at least one metal and one nonmetal.
  - KNO_3 and $Al(NO_3)_3$ are ternary ionic compounds.



NaCl

Molecular Compounds

- ***Binary molecular compounds*** contain two elements and *both* are nonmetals.
  - Some examples of binary molecular compounds are ammonia, NH_3; methane, CH_4; carbon dioxide, CO_2; and tetraphosphorous trisulfide, P_4S_3.



Aqueous Acids

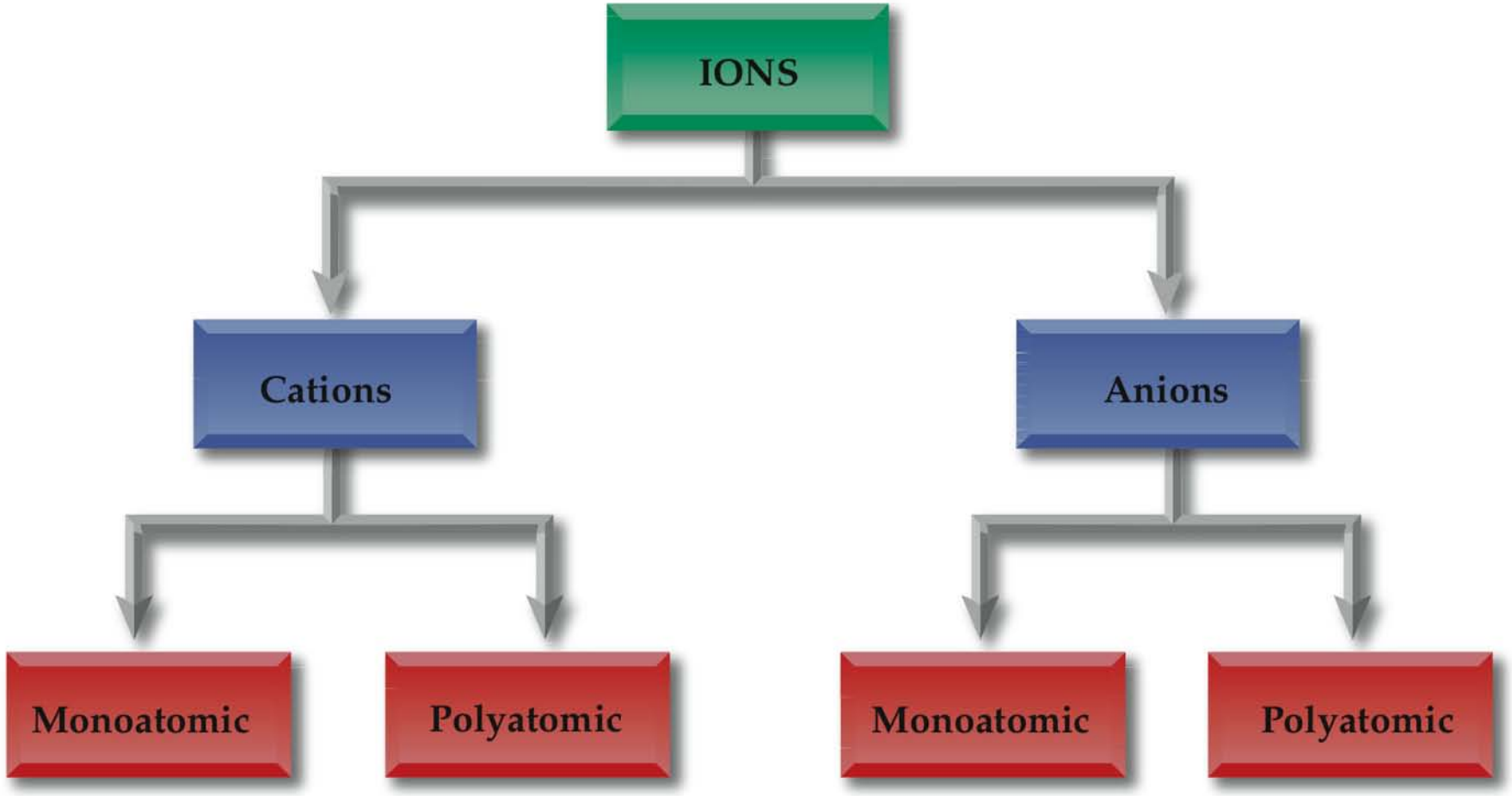
- An ***aqueous solution*** is produced when a compound dissolves in water. It is indicated by the symbol (*aq*).
- A ***binary acid*** is an aqueous solution of a compound containing hydrogen and one other nonmetal. HF (*aq*) is a binary acid.
- A ***ternary oxyacid*** is an aqueous solution of a compound containing hydrogen, oxygen, and one other nonmetal. $HNO_3(aq)$ is a ternary oxyacid.

Classification of Ions

- Recall, an ***ion*** is an atom or group of atoms with a charge.
- A positively charged ion is called a ***cation***.
- A negatively charged ion is called an ***anion***.
- A group of atoms bound together that has an overall charge is called a ***polyatomic anion***.

Classification of Ions, Continued

- Below is a flow chart for the classification of ions.



Monoatomic Cations

- Metal atoms can lose valence electrons and become positively charged cations.
- Cations are named for the parent atom followed by the word “ion.”
  - Na^+ is named “sodium ion.”
  - Al^{3+} is named “aluminum ion.”
- This rule applies for metals that usually form one ion. This includes the main group metals except tin and lead, along with Ag^+, Zn^{2+}, and Cd^{2+}.

Metals that Form Multiple Ions

- If a metal can form more than one cation, it is named for the parent, followed by the charge in Roman numerals in parentheses, followed by the word "ion."
  - Fe^{2+} is the iron(II) ion.
  - Fe^{3+} is the iron(III) ion.
- This is called the ***Stock system*** of naming cations.

Monoatomic Anions

- Nonmetals can gain valence electrons and become negatively charged anions.
- Monoatomic anions are named by dropping the end of the element name and adding the suffix *–ide*.
  - Br^- is the bromide ion.
  - O^{2-} is the oxide ion.
  - N^{3-} is the nitride ion.

Predicting Cation Charges

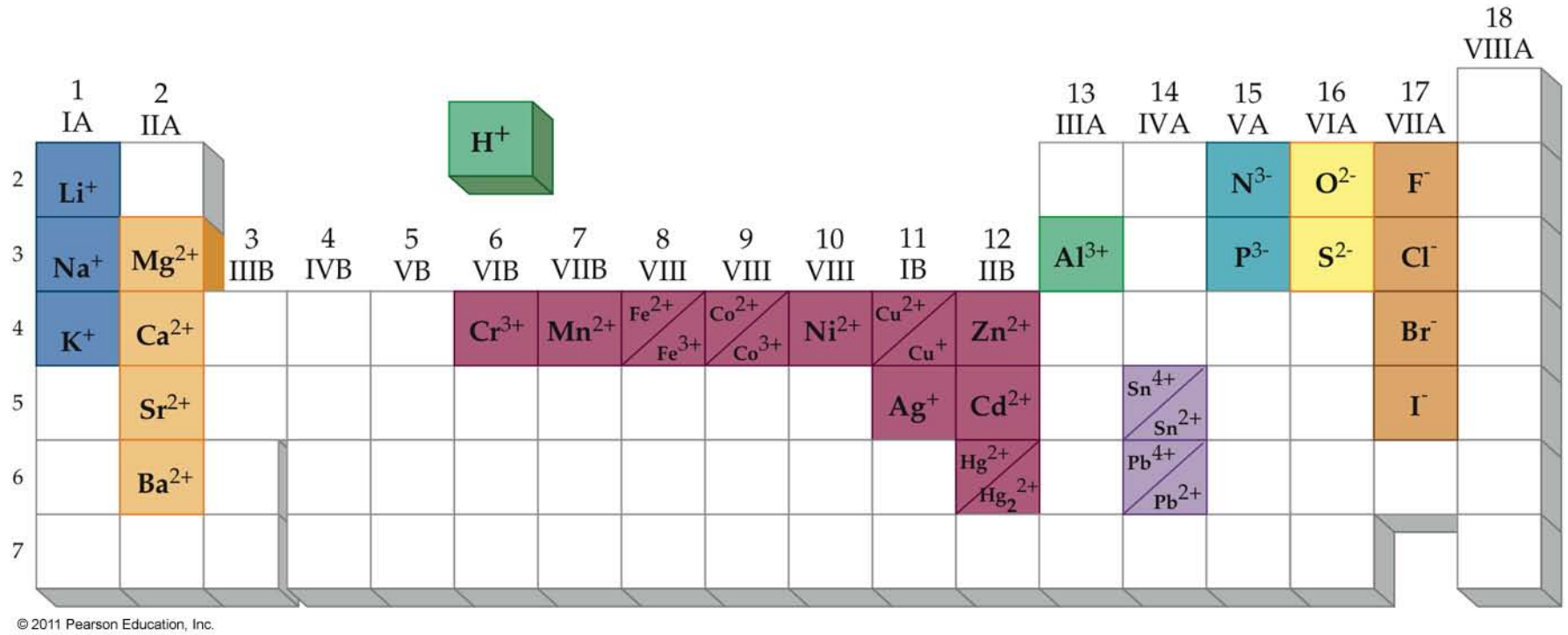
- Recall that Group 1 metals always form +1 ions and Group 2 ions always form +2 ions.
- We can predict that Group 13 ions will form +3 ions.
- Not all metal ion charges are predictable: tin and lead in Group 14 form both +2 and +4 ions.
- Most transition metals form +2 ions from the loss of their two *s* electrons.

Predicting Anion Charges

- Nonmetals gain electrons to form anions in a predictable fashion.
- Group 17 atoms gain one electron to form –1 ions: F^-, Cl^-, Br^-, and I^-.
- Group VIA/16 atoms gain two electrons to form –2 ions: O^{2-}, S^{2-}, Se^{2-}, and Te^{2-}.
- Group VIA/15 atoms gain three electrons to form –3 ions: N^{3-}, P^{3-}, and As^{3-}.

Ion Charges

- Shown are the elements on the periodic table and their common charges.



Polyatomic Anions

- Polyatomic anions generally contain one or more elements combined with oxygen. These anions are called ***oxyanions***.
- Most oxyanions have names that end in the suffix *-ate*.
  - SO_4^{2-} is the sulfate ion.
  - NO_3^- is the nitrate ion.

Naming Oxyanions

- Some oxyanions end in the suffix -*ite*.
  - NO_2^- is the nitrite ion.
  - SO_3^{2-} is the sulfite ion.
- Notice that these oxyanions have one less oxygen: sulfate (SO_4^{2-}) and nitrate (NO_3^-).
- The oxyanions that end in -*ite* each have one less oxygen than the oxyanions that end in -*ate*.

More Polyatomic Anions

- The formula for the chlorate ion is ClO_3^-. What is the formula for the chlorite ion?
  - The suffix has changed from *-ate* to *-ite*. Chlorite must have one less oxygen then chlorate, so its formula is ClO_2^-.
- Notice that the charge does not change as the number of oxygen atoms changes.
- There are two common polyatomic ions that end in *-ide*:
  1. Hydroxide, OH^-
  2. Cyanide, CN^-

Some Common Polyatomic Ions

TABLE 7.3 COMMON POLYATOMIC IONS

CATION		IUPAC NAME	
NH_4^+		ammonium ion	
ANION	**IUPAC NAME**	**ANION**	**IUPAC NAME**
$C_2H_3O_2^-$	acetate ion	OH^-	hydroxide ion*
CO_3^{2-}	carbonate ion	ClO–	hypochlorite ion
ClO_3^-	chlorate ion	NO_3^-	nitrate ion
ClO_2^-	chlorite ion	NO_2^-	nitrite ion
CrO_4^{2-}	chromate ion	ClO_4^-	perchlorate ion
CN^-	cyanide ion*	MnO_4^-	permanganate ion
$Cr_2O_7^{2-}$	dichromate ion	PO_4^{3-}	phosphate ion
HCO_3^-	hydrogen carbonate ion	SO_4^{2-}	sulfate ion
HSO_4^-	hydrogen sulfate ion	SO_3^{2-}	sulfite ion

*Note that the suffix *-ide* is an exception to the general *-ate* and *-ite* rule.

Writing Ionic Formulas

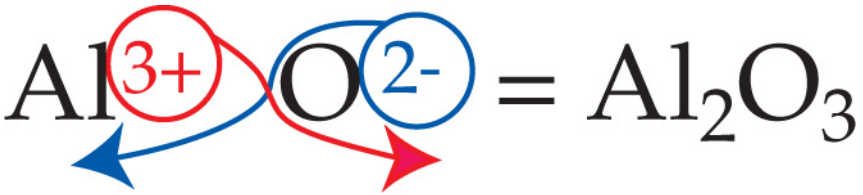
- An ionic compound is composed of positive and negative ions.
- A ***formula unit*** is the simplest representative particle of an ionic compound.
- A formula unit is neutral, so the total positive charge must equal the total negative charge in the formula unit.
- When writing chemical formulas, the cation (metal) goes first and the anion (nonmetal) goes second.

Formulas of Ionic Compounds

- If the ions in the ionic compound have the same charge, the formula unit contains one of each ion.
  - Na^+ and Cl^- combine to form NaCl.
  - Mg^{2+} and S^{2-} combine to form MgS.
- If the charges are not equal, we must balance the positive and negative charges.
  - Ca^{2+} and Cl^- combine to form $CaCl_2$.
  - Na^+ and O^{2-} combine to form Na_2O.

Crossover Rule

- You can quickly verify that the chemical formula is written correctly by crossing over the charge on each ion.



- The charge on the aluminum ion becomes the subscript for the oxygen, and the charge on the oxide ion becomes the subscript for the aluminum ion.

Formulas with Polyatomic Ions

- Follow the same rules as binary ionic compounds; if the charges are equal, the formula has one of each ion.
  - Mg^{2+} and SO_4^{2-} combine to form $MgSO_4$.
  - K^{+} and ClO_3^{-} combine to form $KClO_3$.
- If the charges are not equal, total charge must equal zero. If you have more than one polyatomic ion, it is placed in parentheses.
  - Al^{3+} and CO_3^{2-} combine to form $Al_2(CO_3)_2$.

Determining Ionic Charges

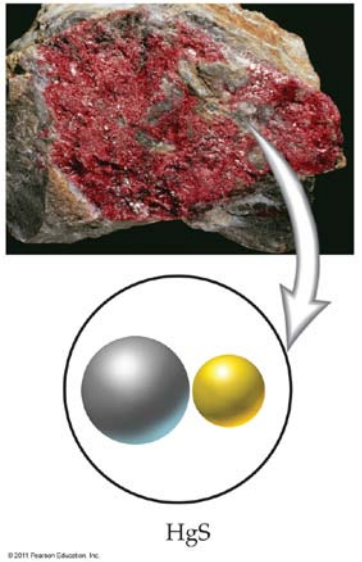
- If an ionic compound contains a metal that can have more than one ionic charge, we must determine the charge on the ion. The sum total charge of an ionic compound must equal zero.
- What is the charge on the chromium ion in Cr_3N_2?
  - The charge on a nitride ion is always –3, so we have a total of six negative charges (2 N^{3-} = 6 negative).
  - The sum of the charges on the chromium ions must be six positive.
  - $Cr^{x+} + Cr^{x+} + Cr^{x+}$ = 6 positive $\Rightarrow$ Each Cr is 2+.

Critical Thinking: Potassium

- Potassium is an extremely reactive element (its violent reaction with water is pictured below).
- How can such a reactive element (with water) be essential for human life?
- The potassium ion (K^+) is essential, not the free element.
- Good sources of potassium include fish, meat, fruit, dark vegetables, and nuts.

Naming Binary Ionic Compounds

- When naming ionic compounds, we combine the cation and anion name (drop the word “ion”), with the cation first and the anion second.
- MgO is composed of one magnesium ion and one oxide ion, therefore the name is magnesium oxide.
- What is the name of cinnabar, HgS?
- Hg^{2+} is the mercury(II) ion and S^{2-} is the sulfide ion, so the name is mercury(II) sulfide.



Formulas for Binary Ionic Compounds

- We can determine formula of a binary ionic compound from its name.
- What is the formula of iron(III) fluoride?

  Iron(III) has a +3 charge, Fe^{3+}; and fluoride has a –1 charge, F^-.

- Since the total charge must equal zero, the formula for iron(III) fluoride is FeF_3.

$$+3 + 3(-1) = \text{zero}$$

Naming Ternary Ionic Compounds

- We name ternary ionic compounds like binary ionic compounds: the cation name followed by the anion name.
- K_2CO_3 is named potassium carbonate.
- If we have a metal that can have than one oxidation state, we have to determine the charge on the metal.
- $Co(ClO_3)_3$ is composed of cobalt(III) and chlorate ions, so its name is cobalt(III) chlorate.

Formulas for Binary Compounds

- We can predict the formula of an ionic compound based on the formula of a similar compound.
- What is the formula of radium carbonate given that calcium carbonate is $CaCO_3$?

  Radium, Ra, and calcium are both in Group 2 and will have the same ionic charge.
- The formula for radium carbonate is $RaCO_3$.

Binary Molecular Compounds

- Binary molecular compounds are composed of two *nonmetal* elements.
- A ***molecule*** is the simplest representative particle of a binary molecular compound.
- IUPAC has set the following order for writing the elements in a binary molecular compound:
  - C, P, N, H, S, I, Br, Cl, O, and F
- Notice they are arranged according to increasing electronegativity.

Naming Binary Molecular Compounds

- The first element in the compound is named first and the second element has the suffix *-ide*.
- The number of atoms of each element must be indicated by Greek prefixes.

TABLE 7.4 GREEK PREFIXES FOR BINARY MOLECULAR COMPOUNDS

ATOMS	PREFIX	ATOMS	PREFIX
1	*mono-*	6	*hexa-*
2	*di-*	7	*hepta-*
3	*tri-*	8	*octa-*
4	*tetra-*	9	*nona-**
5	*penta-*	10	*deca-*

*Although the Latin prefix *nona-* is commonly used, IUPAC prefers the Greek prefix *ennea-*.

Naming Binary Molecular Compounds, Continued

- The molecular compound P_4S_3 is used on match tips. What is the name of P_4S_3?
  - There are 4 P atoms, use *tetra*-.
  - There are 3 S atoms, use *tri*-.
  - The name for P_4S_3 is tetraphosphorous trisulfide.
- What is the name for N_2O_4?
  - Dinitrogen tetraoxide

An Exception

- There is one exception to the use of the Greek prefixes when naming binary molecular compounds.
- If there is only one atom of the first element, the *mono*- is not used. The prefix *mono*- is always used for the second element.
  - CO is carbon monoxide.
  - XeF_6 is xenon hexafluoride.

Binary Acids

- A ***binary acid*** is an aqueous solution of a compound containing hydrogen and a nonmetal.
- The formula of an acid always begins with H:
  - HF (*aq*)
- Binary acids are named by using the prefix *hydro-* before the element stem and adding the suffix *-ic acid*.
  - HF (*aq*) is hydrofluoric acid.
  - HI (*aq*) is hydroiodic acid.

Ternary Oxyacids

- ***Ternary oxyacids*** are aqueous solutions of a compound containing hydrogen and an oxyanion.
- If the acid is derived from an oxyanion ending in *-ate*, the suffix is changed to *-ic acid*.
  - HNO_3 (*aq*) is nitric acid (from NO_3^-, nitrate ion).
- If the acid is derived from an oxyanion ending in *-ite*, the suffix is changed to *-ous acid*.
  - HNO_2 (*aq*) is nitrous acid (from NO_2^-, nitrite ion).

Oxyanions and Oxyacids

- Below is an example of ternary oxyacid and ternary compound naming.

Ternary Oxyacid		Ternary Compound	
$HClO$	**hypo**chlor**ous** acid	$NaClO$	sodium **hypo**chlor**ite**
$HClO_2$	chlor**ous** acid	$NaClO_2$	sodium chlor**ite**
$HClO_3$	chlor**ic** acid	$NaClO_3$	sodium chlor**ate**
$HClO_4$	**per**chlor**ic** acid	$NaClO_4$	sodium **per**chlor**ate**

Chapter Summary

- Most inorganic compounds do not contain carbon.
- Binary ionic compounds are composed of a metal and a nonmetal.
- Ternary ionic compounds are composed of a metal, a nonmetal, and oxygen.
- Binary molecular compounds are composed of two nonmetal elements.
- Acids are composed of hydrogen and a nonmetal atom or an oxyanion.

Chapter Summary, Continued

- Cations are named the element plus the word *ion*.
- Cations with more than one possible charge have their charge indicated with Roman numerals in parentheses.
- Ionic compounds are named using the cation first, anion second. Then anion has the suffix *-ide* added.
- The simplest representative unit for an ionic compound is a ***formula unit***.

Chapter Summary, Continued

- The simplest representative unit for a molecular compound is a ***molecule***.
- When naming molecular compounds, the elements are written in the order C, P, N, H, S, I, Br, Cl, O, then F.
- The name of the first element is the same; the suffix -*ide* is added to the second element.
- Greek prefixes are used to indicate the number of each atom in the formula.

Chapter Summary, Continued

- An acid is an aqueous solution of a compound containing hydrogen and a nonmetal or an oxyanion.
- Binary acids are named for the nonmetal atom by adding the prefix -*hydro* and the suffix -*ic acid*.
- Ternary oxyacids are named by changing the -*ate* suffix on the oxyanion to -*ic acid*, or the -*ite* suffix on the oxyanion to -*ous acid*.