Compounds, Formulas & Nomenclature

Chapter 2

Molecular Compounds

- A *molecule* is a collection of atoms that are covalently bound (share electrons).
- A molecule acts as a single, free entity and is smallest units of ***covalent compounds.***
- The *formula* for a molecular compound is the number of atoms of various elements in a single molecule.
- *Examples:* H_2O $C_{12}H_{22}O_{11}$ SO_2

Ionic Compounds

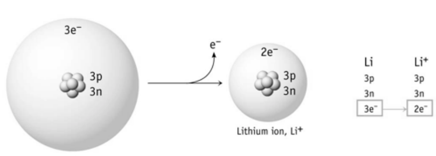
- An ion is an atom (or group of bonded atoms) that has lost or gained electrons, resulting in a charge.
- An ionic compound is formed when positively charged ions and negatively charged ions attract
- Ionic compounds are neutral.
- The *formula* for an ionic compound is the smallest whole number ratio of ions in a compound. This is the *formula unit*.
- Ions in an ionic compound form crystals - a lattice of repeating positive and negative ions.
- *Examples:* $NaCl$, Fe_2O_3, $Al(SO_4)_3$

Ion formation

- **Valence electrons** are the outermost electrons in an atom. These electrons participate in bonding of atoms.
- **Cations** are atoms that have a positive charge.
- **Anions** are atoms that have a negative charge.
- **Monatomic Ions** are ions composed of a single atom.
- **Polyatomic Ions** are ions composed of two or more atoms.

Cations

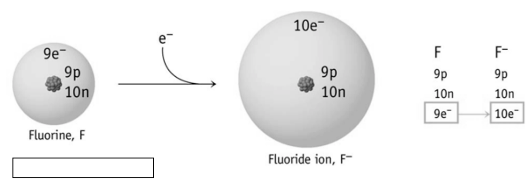
- Metals tend to ***LOSE*** electrons to achieve an ***octet*** – 8 valence electrons.
- Neutral metals are oxidized to form CATIONS (positive ions).
- The process of oxidation involves the **loss of one or more electrons**.



- *Other examples:* $Ba \rightarrow Ba^{+2} + 2e^-$
  $Al \rightarrow Al^{+3} + 3e^-$

Anions

- Non-metals generally GAIN electrons to achieve an octet.
- Neutral non-metals are reduced to form ANIONS (negative ions).
- The process of reduction involves the **gaining of one or more electrons**.



- *Other examples:* $S + 2e^- \rightarrow S^{2-}$
  $Cl + 1e^- \rightarrow Cl^-$

Predicting the Charges of Monatomic Ions:

- The periodic table can help us to determine what the charge on ions will be.
- Noble gases (group 8A) have a very stable electron configuration, and generally do not form ions. They are ***inert***, or ***non-reactive***.
- A - group elements usually gain or lose electrons to get the same number of electrons as a noble gas.
- Ions formed from ***A - group*** metals and non-metals have very predictable charges that can be determined from their placement on the table.

Predicting the Charges of Monatomic Ions:

- Ions formed from **metals** in groups 1A, 2A, and 3A have *positive charges* equal to their *group number*.
  Na forms +1 ions, Sr forms +2 ions, and Al forms +3 ions.
- **Non-metals** generally form ions that have charges that are equal to their distance from the end of the row.
- The Halogens (group 7A) elements form **– 1** ions, because they want to gain one electron to have the same number of electrons as a Noble Gas.
- The non-metals in the Oxygen group form **–2** ions and those in the Nitrogen group form **– 3** ions.

Predicting the Charges of Monatomic Ions:

- In general, Carbon and many of the metalloids do not form ions, but instead make covalent compounds.
- For other metals on the periodic table, it is harder to predict the charges of their ions,
- The transition metals, or B-group metals, often form more than one kind of cation. The names of these elements will include a roman numeral that tells the charge.
- Also, the metals below the non-metals (p-block) often have more than one possible charge and require a Roman numeral to indicate their charge.
- *Examples:*

Iron (II) = Fe^{2+} | **Lead (II) = Pb^{2+}**

Iron (III) = Fe^{3+} | **Lead (IV) = Pb^{4+}**

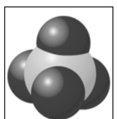
Roman Numerals

One = I	**Seven = VII**
Two = II	**Eight = VIII**
Three = III	**Nine = IX**
Four = IV	**Ten = X**
Five = V	**Eleven = XI**
Six = VI	**Twelve = XII**

Polyatomic Ions

- ***Polyatomic ions*** *are ions composed of more than one atom.*
- Polyatomic ions may be cations or anions.
- They are covalently bound groups of atoms that have lost or gained electrons.
- Polyatomic ions are "molecules with a charge".

Sulfate Oxoanion



SO_4^{2-}

Ion name	*Ion Formula*
ammonium	**NH_4^+**
cyanide	**CN^-**
hydroxide	**OH^-**
nitrate	**NO_3^-**
nitrite	NO_2^-
sulfate	**SO_4^{2-}**
sulfite	SO_3^{2-}
hydrogen sulfate (bisulfate)	HSO_4^-
carbonate	**CO_3^{2-}**

Ion name	*Ion Formula*
hydrogen carbonate (bicarbonate)	HCO_3^-
phosphate	**PO_4^{3-}**
hydrogen phosphate	HPO_4^{2-}
dihydrogen phosphate	$H_2PO_4^-$
permanganate	**MnO_4^-**
perchlorate	ClO_4^-
chlorate	**ClO_3^-**
chlorite	ClO_2^-
hypochlorite	ClO^-

General Properties of Ionic Compounds

- All ionic compounds are neutral, and composed of cations and anions whose charges cancel (add up to zero).
- The *formula unit* is the smallest ratio of cations and anions.
- Many ionic compounds are composed of a metal and a non-metal.
- In other cases, the cation and/or anion is a polyatomic ion.

Predicting Formulas of a Ionic Compounds:

- What is the formula for a compound formed by the combination of magnesium ions and chloride ions?

Mg *forms +2 ions.* **Cl** *forms -1 ions.*

- Because compounds are NEUTRAL, one Mg^{+2} ion will combine with two Cl^{-1} ions.
- Therefore, the formula for magnesium chloride is **$MgCl_2$**.

Predicting Formulas of Ionic Compounds:

- **When writing formulas:**
  - **the cation (often a metal) is always written first**
  - **the anion (often a non-metal) is always written second.**
- **The SMALLEST ratio of cation to anion is always written.**
- **The charges on the ions are not usually written in the formula of the ionic compound.**
- **The formula for magnesium chloride is $MgCl_2$**

not **Mg_2Cl_4** ***not*** **$Mg^{2+}Cl^{-}_2$.**

Predicting Formulas of Ionic Compounds

- We can always reason out how the charges cancel by adding them up. However, there is a simpler way:
- What is the formula for an ionic compound made up of aluminum and oxygen?

Al *forms +3 ions.* **O** *forms -2 ions.*

- To find the formula, simply write both ions in correct order, and CROSS charges:

$Al^{+3}\ O^{-2}$ Al_2O_3

- The compound is neutral:

2 x (Al^{+3}) = +6
3 x (O^{-2}) = -6
0 (neutral)

Considering Polyatomic Ions in writing formulas:

- In some cases, the metal or non-metal is replaced by a polyatomic ion. The polyatomic ion is simply treated as a SINGLE UNIT.
- What is the formula for the combination of potassium ions and nitrate ions into an ionic compound?

K *forms +1 ions.* **Nitrate (NO_3^{-1})** *is a -1 ion.*

- The formula for potassium nitrate is **KNO_3**.

Considering Polyatomic Ions in writing formulas:

- **What is the formula for the combination of Aluminum and sulfate ions?**

$Al^{+3}\ SO_4^{-2}$

$Al_2(SO_4)_3$

- ***Parentheses must be used when more than one of the same polyatomic ion is in the formula unit.***

Write formulas for IONIC compounds:

1. Potassium bromide
2. Sodium oxide
3. Strontium phosphide
4. Aluminum sulfide
5. Ammonium sulfate
6. Nickel (II) phosphate
7. Magnesium nitrite
8. Lead (IV) selenide

Binary Ionic Compounds

- Binary means "two".
- Any compound composed of just two **elements** *(not necessarily two atoms)* is a binary compound.
- A **binary ionic compound** is composed of a metal and a non-metal.
- Examples: $NaCl$ $MgBr_2$ Al_2O_3
- Ionic compounds with a polyatomic ion are NOT binary ionic compounds, as they will have more than two atoms.
- For example, $Mg(NO_3)_2$ is NOT a binary compound.

Naming IONIC compounds

- Naming ionic compounds is easy. You simply write the name of the CATION followed by the name of the ANION.

Naming the CATION

- If it is a ***Group A metal (representative elements)***, simply use the name of the metal.
- If the cation is a ***polyatomic ion***, use the name of the ion. *Note that the only common polyatomic cation is ammonium* **(NH_4^+)**.

Naming the CATION

If the cation is a ***Transition metal***, use the name of the element and a Roman Numeral signifying the charge.

Cu^{+2} = *copper (II)* Cu^{+1} = *copper (I)*

Mn^{+7} = *manganese (VII)* Mn^{+2} = *manganese (II)*

- EXCEPTIONS:
  No Roman Numeral is needed for naming.
  - Zn always forms +2 ions
  - Cd always forms +2 ions
  - Ag always forms +1 ions

Naming the CATION

- If the cation is a metal in the p-block of the periodic table (underneath the stair-step line), it may also need a Roman numeral to signify its charge.
  - **Pb** and **Sn** both may have +2 or +4 charges:

    Pb^{2+} = lead (II) Pb^{4+} = lead (IV)
  - **Tl** and **In** both may have +1 or +3 charges:

    In^{+} = Indium (I) In^{3+} = Indium (III)

Naming the ANION

If the anion is a non-metal, then follow these 2 steps:

1. Drop the suffix on the element name.
2. Add ***–ide***.
   - Example:

     For chlorine, drop the –ine and add –ide.

     The name of chlorine as an anion is *chloride*.
   - Other Examples:

     Fluorine → fluoride

     Oxygen → oxide

     Phosphorus → phosphide

Naming the ANION

- If the anion is a ***polyatomic ion***, use the name of the ion. *See table in the book.*
- Note that most polyatomic anions end in ***–ite*** or ***–ate***.
- Exceptions:
  - OH^- = hydroxide
  - CN^- = cyanide

Systematic Polyatomic Ion Names

Consider the chlorine oxoanion series:

ClO_4^-	per-*chlor*-ate	The ion with one additional oxygen gets a prefix of ***per–*** and a suffix of ***–ate***.
ClO_3^-	*chlor*-ate	The most common ion in a series gets the suffix ***–ate***.
ClO_2^-	*chlor*-ite	The ion with one fewer oxygen gets the suffix ***–ite.***
ClO^-	hypo-*chlor*-ite	The ion with two fewer oxygens gets a prefix of ***hypo–*** and a suffix of ***–ite***.

Polyatomic Ions and Hydrogen

- Many polyatomic oxoanions form acids when hydrogen ion covalently bond to one of the oxygens. For example:

  carbonate ion = CO_3^{2-}

  carbonic acid = H_2CO_3

- However, sometimes the ion will take on fewer hydrogens than need to fully cancel the charge, and you still have a polyatomic ion:

  hydrogen carbonate ion = HCO_3^-

  This ion is also known as bicarbonate.

Sulfur oxoanions

SO_4^{2-} = sulfate ion

SO_3^{2-} = sulfite ion

HSO_4^- = hydrogen sulfate ion *or* bisulfate ion

Phosphorus oxoanions

PO_4^{3-} = phosphate ion

HPO_4^{2-} = hydrogen phosphate ion

$H_2PO_4^-$ = dihydrogen phosphate ion

Write Names for these IONIC Compounds

1) Na_2SO_3
2) Na_2S
3) $Fe(NO_3)_2$
4) $FeCl_3$
5) W_3P_4
6) Mn_2O_7
7) $Ca_3(PO_4)_2$
8) $(NH_4)_2CrO_4$
9) ZnI_2
10) $PbSO_4$

Names and Formulas for BINARY Molecular (Covalent) Compounds

- Binary molecular compounds are composed of two non-metals.
- The ratios in which they combine are not as predictable as they are for IONIC compounds.
- *For example, C and H can form compounds with many different formulas, including* CH_4, C_3H_8, $C_{50}H_{102}$.

Formulas & Naming: Covalent Compounds

Rules for naming molecular compounds:

1. The ***first*** element in the formula is named by its name on the periodic table.
2. The ***second*** element is named as it would be if it were the anion of the element.
   *(Though it is **not** the anion!)*
3. Use ***prefixes*** to indicate how many of each element is present.

   Exception: If only one of the FIRST element in the formula is present, do NOT use the prefix *mono-*. Just leave it off.

Prefixes for Naming Covalent compounds:

# of atoms of element	Prefix
1	mono-
2	di-
3	tri-
4	tetra-
5	penta-
6	hexa-
7	hepta-
8	octa-
9	nona-
10	deca-
11	undeca-
12	dodeca-

Binary Covalent Compounds – Examples

- *Write the name or formula:*
  1. CO
  2. CO_2
  3. N_2O_5
  4. N_2O
  5. NO_2
  6. P_4O_{10}
  7. Sulfur trichloride
  8. Oxygen difluoride
  9. Disulfur trioxide

Common Names

- Many compounds – both molecular and ionic – are known by their common names.
- There are three common molecular compounds with special names that you need to know:

Water	H_2O
Ammonia	NH_3
Methane	CH_4

Naming Acids

- Acids are compounds that have a Hydrogen that can dissociate in water.
- Acids are named using the name of the anion as the root as shown in the table below.

Anion SUFFIX	Acid Name	Example:
-ide	Hydro-*root*-ic acid	**HCl** anion = chloride Acid name = hydrochloric acid
-ate	-ic acid	**$HClO_3$** anion = chlorate Acid name = chloric acid
-ite	-ous acid	**$HClO_2$** anion = chlorite Acid name = chlorous acid

Writing Acid names and formulas

1) HNO_3
2) H_2SO_3
3) $HBrO_3$
4) HBr
5) Phosphoric acid
6) Hydrocyanic acid
7) Nitrous acid
8) Hydrofluoric acid

Naming Compounds – Summary

1. Determine the type of compound you are trying to name:
   - Ionic
   - Covalent (molecular)
   - Acid
2. Use the appropriate naming scheme.

Acetate ion

- The **acetate anion** is an organic (carbon-containing) ion.
- It is often written as a structural formula.
- The following formulas both represent the acetate ion and are equally valid:

  $CH_3CO_2^-$ $C_2H_3O_2^-$

- **Acetic acid** is an organic acid composed of a hydrogen ion covalently bound to the acetate ion.
- Because organic acids are often written as structural formulas, the acid "H" is not always at the start of the formula. Both of the following formulas are valid for acetic acid:

  CH_3CO_2H $HC_2H_3O_2$

Hydrates

- Hydrates are compounds that crystallize with water molecules in their crystal lattice. Hydrates contain a specific ratio of water molecules to formula units.
- *Naming Hydrates:*

  The name of a hydrate is simply the name of the compound followed by an indication of the number of waters of hydration.

  $ZnSO_4 \cdot 4\ H_2O$ = zinc sulfate tetrahydrate

The Diatomic Elements – Review

- Seven elements exist as ***diatomic molecules*** in their elemental form.
- For example, Oxygen is an element. However, Oxygen in the air is not simply O atoms, but as O_2 molecules.
- *The diatomic elements are:*

  H_2 O_2 N_2 F_2 Cl_2 Br_2 I_2

- ***Note:*** These elements are necessarily diatomic only when alone as elements. They will sometimes have other subscripts in compounds.

Calculating Molar Masses for Compounds

- Molar mass is the most general term of the mass of one mole of an element or compound.
- Also used are: atomic mass, formula mass, and molecular mass depending on the material described. Or, the word weight might substitute for mass.
- To calculate the molar mass for a compound, dd together the atomic masses for all of the atoms in a molecule or formula unit of the compound.
- Units may be expressed as **amu** or $^{g}/_{mol}$