Molecular Compounds

*Molecular Formulas*

exact number of atoms of each type in compound

- example - \( \text{H}_2\text{O} \)

- **inorganic compounds**
  - contain no carbon
    - examples - \( \text{NH}_3 \), \( \text{H}_2\text{SO}_4 \), \( \text{P}_2\text{O}_5 \)
  - many are ionic

- **organic compounds**
  - contain carbon
    - examples - \( \text{C}_2\text{H}_6 \), \( \text{C}_2\text{H}_6\text{O} \), \( \text{C}_3\text{H}_8 \)
  - generally molecular
Molecular Compounds

**Molecular Formulas**

- **methods for writing formulas**
  - **molecular formula**
    - \( \text{C}_2\text{H}_6 \) (ethane) \( \text{C}_2\text{H}_6\text{O} \) (ethanol)
  - **structural formula**
    - \( \text{CH}_3\text{CH}_3 \)
    - \( \text{CH}_3\text{CH}_2\text{OH} \)
  - **condensed formula**
    - \( \text{CH}_3\text{CH}_3 \)
    - \( \text{CH}_3\text{CH}_2\text{OH} \)

- **Functional group**
  - (hydroxide)
Naming Binary Inorganic Compounds

molecules containing atoms of only two elements

- element farthest left first
  - HCl \((\text{hydrogen chloride})\)
- if same group - lowest first
  - \(\text{SO}_2\)
- second element ends in \(-\text{ide}\)

- Greek prefixes for numbers
  - exception - binary hydrogen compounds
    - example: \(\text{H}_2\text{S}\) - hydrogen sulfide
# Naming Binary Inorganic Compounds

## TABLE 3.2 Prefixes Used in Naming Chemical Compounds

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-</td>
<td>1</td>
</tr>
<tr>
<td>Di-</td>
<td>2</td>
</tr>
<tr>
<td>Tri-</td>
<td>3</td>
</tr>
<tr>
<td>Tetra-</td>
<td>4</td>
</tr>
<tr>
<td>Penta-</td>
<td>5</td>
</tr>
<tr>
<td>Hexa-</td>
<td>6</td>
</tr>
<tr>
<td>Hepta-</td>
<td>7</td>
</tr>
<tr>
<td>Octa-</td>
<td>8</td>
</tr>
<tr>
<td>Nona-</td>
<td>9</td>
</tr>
<tr>
<td>Deca-</td>
<td>10</td>
</tr>
</tbody>
</table>

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Naming Binary Inorganic Compounds

compounds with common, nonsystematic names:

- $\text{H}_2\text{O}$ water
- $\text{NH}_3$ ammonia
- $\text{N}_2\text{H}_4$ hydrazine
- $\text{NO}$ nitric oxide
- $\text{N}_2\text{O}$ nitrous oxide
- $\text{PH}_3$ phosphine

(text p. 82)
Hydrocarbons

- contain only C and H
- simplest type is alkanes
  - general formula - $C_nH_{2n+2}$ (n = integer)
  - first 4 have common names - remaining systematic
# Hydrocarbons

## Table 3.4 The First Ten Alkane Hydrocarbons, $C_nH_{2n+2}$

<table>
<thead>
<tr>
<th>Molecular Formula</th>
<th>Name</th>
<th>Boiling Point (°C)</th>
<th>Physical State at Room Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_4$</td>
<td>Methane</td>
<td>$-161.6$</td>
<td>Gas</td>
</tr>
<tr>
<td>C$_2$H$_6$</td>
<td>Ethane</td>
<td>$-88.6$</td>
<td>Gas</td>
</tr>
<tr>
<td>C$_3$H$_8$</td>
<td>Propane</td>
<td>$-42.1$</td>
<td>Gas</td>
</tr>
<tr>
<td>C$<em>4$H$</em>{10}$</td>
<td>Butane</td>
<td>$-0.5$</td>
<td>Gas</td>
</tr>
<tr>
<td>C$<em>5$H$</em>{12}$</td>
<td>Pentane</td>
<td>$36.1$</td>
<td>Liquid</td>
</tr>
<tr>
<td>C$<em>6$H$</em>{14}$</td>
<td>Hexane</td>
<td>$68.7$</td>
<td>Liquid</td>
</tr>
<tr>
<td>C$<em>7$H$</em>{16}$</td>
<td>Heptane</td>
<td>$98.4$</td>
<td>Liquid</td>
</tr>
<tr>
<td>C$<em>8$H$</em>{18}$</td>
<td>Octane</td>
<td>$125.7$</td>
<td>Liquid</td>
</tr>
<tr>
<td>C$<em>9$H$</em>{20}$</td>
<td>Nonane</td>
<td>$150.8$</td>
<td>Liquid</td>
</tr>
<tr>
<td>C$<em>{10}$H$</em>{22}$</td>
<td>Decane</td>
<td>$174.0$</td>
<td>Liquid</td>
</tr>
</tbody>
</table>
Ions and Ionic Compounds

Ionic compound - composed of positive and negative ions

- typically metal with non-metal
  - metal loses electrons to form cation
  - non-metal gains electrons to form anion

Example - NaCl  (formed from Na\(^+\) and Cl\(^-\))
Ionic Charges

determine charges of monatomic ions from Periodic Table

- Hydrogen appears twice because it can gain or lose an electron.

- Transition metals can lose varying numbers of electrons, forming cations with different charges.
Ionic Compounds

formed from a cation(s) and an anion(s)

- overall charge on formula is neutral
  - examples:
    - $\text{Na}^+ & \text{Cl}^-$ $\rightarrow$ $\text{NaCl}$
    - $\text{Ca}^{2+} & \text{Cl}^-$ $\rightarrow$ $\text{CaCl}_2$
    - $\text{Mg}^{2+} & \text{N}^{3-}$ $\rightarrow$ $\text{Mg}_3\text{N}_2$

- “empirical” formulas only

- write formula: cation then anion
Naming Ionic Compounds

Cations

- Cations from metals
  - same name as metal
    - $\text{Na}^+$ sodium ion
    - $\text{Ca}^{2+}$ calcium ion

- Same metal, differing charges
  - use Roman numeral to distinguish
  - usually transition metals
    - $\text{Fe}^{2+}$ iron(II) ion
    - $\text{Fe}^{3+}$ iron(III) ion

- Cations from non-metals
  - names end in $-\text{ium}$
    - $\text{NH}_3$ ammonia
    - $\text{NH}_4^+$ ammonium
Naming Ionic Compounds

**Anions**

- **Monatomic**
  - drop ending, add *-ide*
    - $\text{H}^-$ hydride ion
    - $\text{O}^{2-}$ oxide ion

- **Polyatomic**
  - oxoanions (if only 2 possible - *e.g.* $\text{N, S, P}$)
    - larger # of O atoms - suffix *-ate*
      - $\text{NO}_3^-$ nitrate ion
      - $\text{SO}_4^{2-}$ sulfate ion
    - smaller # of O atoms - suffix *-ite*
      - $\text{NO}_2^-$ nitrite ion
      - $\text{SO}_3^{2-}$ sulfite ion
Naming Ionic Compounds

Anions (cont’d)

- Polyatomic (cont’d)
  - o xoanions  (if more than two possible - e.g. Cl, Br, I)
    - largest # of O atoms - prefix *per-* + suffix *-ate*
      - ClO$_4^-$ perchlorate ion
      - IO$_4^-$ periodate ion
    - next largest # of O atoms - suffix *-ate*
      - ClO$_3^-$ chlorate ion
      - IO$_3^-$ iodate ion
    - third largest # of O atoms - suffix *-ite*
      - ClO$_2^-$ chlorite ion
      - IO$_2^-$ iodite ion
    - smallest # of O atoms - prefix *hypo-* + suffix *-ite*
      - ClO$^-$ hypochlorite ion
      - IO$^-$ hypoiiodite ion
Naming Ionic Compounds

Anions (cont’d)

- Polyatomic (cont’d)
  - Oxoanions with hydrogen
    - Name oxoanion portion according to rules
    - Place “hydrogen” in front of oxoanion name
    - Notice that the charge on the anion has increased (become more positive) by the same amount as the number of \( H^+ \) ions added
### Naming Ionic Compounds

#### Anions (cont'd)

- Polyatomic anions with nonstandard names

<table>
<thead>
<tr>
<th>AnionSymbol</th>
<th>ChemicalName</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH$_3$COO$^-$</td>
<td>acetate ion</td>
</tr>
<tr>
<td>CN$^-$</td>
<td>cyanide ion</td>
</tr>
<tr>
<td>C$_2$O$_4^{2-}$</td>
<td>oxalate ion</td>
</tr>
<tr>
<td>OH$^-$</td>
<td>hydroxide ion</td>
</tr>
<tr>
<td>O$_2^{2-}$</td>
<td>peroxide ion</td>
</tr>
<tr>
<td>O$_2^-$</td>
<td>superoxide ion</td>
</tr>
<tr>
<td>MnO$_4^-$</td>
<td>permanganate ion</td>
</tr>
<tr>
<td>CrO$_4^{2-}$</td>
<td>chromate ion</td>
</tr>
<tr>
<td>Cr$_2$O$_7^{2-}$</td>
<td>dichromate ion</td>
</tr>
</tbody>
</table>
Naming Ionic Compounds

- Cation then anion

examples:

CaCl$_2$  calcium chloride
MgSO$_4$  magnesium sulfate
(NH$_4$)$_2$CO$_3$  ammonium carbonate
Properties of Ionic Compounds

- metal + nonmetal
- crystalline
- hard, brittle
- high melting points
- high boiling points
- electrolytes
Percent Composition

composition of any compound expressed by

- # atoms of each type per molecule or formula unit
- mass of each element in a mole of compound

% by mass of each element in compound  \( \text{(part/whole)} \times 100\% \)

example:  \( \text{C}_{12}\text{H}_{22}\text{O}_{11} \)

\[
\begin{align*}
\% \text{C} &= \frac{12(12.011 \text{ g/mol})}{342.299 \text{ g/mol}} \times 100\% = 42.107\% \\
\% \text{H} &= \frac{22(1.0079 \text{ g/mol})}{342.299 \text{ g/mol}} \times 100\% = 6.4779\% \\
\% \text{O} &= \frac{11(15.9994 \text{ g/mol})}{342.299 \text{ g/mol}} \times 100\% = 51.4151\%
\end{align*}
\]
Empirical Formulas

ratio of mol of each element gives subscripts

$\text{H}_2\text{O}$ - empirical formula for water

2 atoms H + 1 atom O  OR  2 mol H + 1 mol O

Mass % of element

assume 100 g sample

Grams of each element

use atomic mass

Empirical Formula

calc. mol ratio
(divide each by smallest # mol)

Moles of each element
Molecular Formula

need:
- empirical formula
- molar mass of molecular formula

Empirical Formula

Molecular Formula

Molar mass of empirical formula

# to multiply empirical formula by

multiply
calculate
molar mass of molecular
molar mass of empirical