Compounds: Introduction to Bonding

Most elements exist as compounds in combination with other elements.

Compounds are formed by an exchange of electrons.

Two types of compounds:

- **Ionic**: as a result of *transferring electrons*
- **Covalent**: as a result of *sharing electrons*

Ionic Compounds: Formation

Ions: charged particles formed from atoms or groups of atoms

**Cations (+)**: *positively charged ions (i.e. from metals)*

**Anions (-)**: *negatively charged ions (i.e. from non-metals)*

Ionic “bonding” is a result of electrostatic attraction

\[ E \propto \frac{\text{charge}(1) \times \text{charge}(2)}{\text{distance}} \]
Ionic Compounds: Formation

All elements want to be like noble gases that is, to have the same number of electrons (the same electronic configuration)

Example: Sodium Chloride, NaCl, Na⁺Cl⁻:

Na(11 electrons) - 1 e⁻ = Na⁺ (10 electrons); like Ne
Cl (17 electrons) + 1 e⁻ = Cl⁻ (18 electrons); like Ar
Ionic Compounds: Formation

All elements want to be like noble gases that is, *to have the same number of electrons*

**Main group elements:**

Group 1 *alkali metals*: lose **one** electron $\rightarrow M^+$
Group 2 *alkaline earth metals*: lose **two** electrons $\rightarrow M^{2+}$
Group 3 metals: lose **three** electrons $\rightarrow M^{3+}$

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Ionic Compounds: Formation

All elements want to be like noble gases that is, *to have the same number of electrons*

**Main group elements:**

Group 7 *halogens*: acquire **one** electron $\rightarrow A^-$
Group 6 elements: acquire **two** electrons $\rightarrow A^{2-}$
Group 5 elements: acquire **three** electrons $\rightarrow A^{3-}$
Ionic Compounds: Structure

NO bonds in solid or liquid state

NaCl

But a continuous network of ions

Covalent Compounds: Real Bonds

Non-metals SHARE electrons to attain the nearest noble gas electron count (electronic configuration).

Simplest case: Hydrogen

H• + H• = H:H = H₂  compare to He:
Covalent Compounds: Real Bonds

*Non-metals SHARE electrons* to attain the nearest noble gas electron count (electronic configuration).

Another example: Oxygen

\[ \text{O}^{\cdot} + \text{O}^{\cdot} = \text{O}^{\cdot\cdot}\text{O} = \text{O}_2 \]

compare to Ne

Non-metals SHARE electrons to attain the nearest noble gas electron count (electronic configuration).

More complex example: Oxygen and Hydrogen

\[ \text{H}^{\cdot} + \cdot\text{O}^{\cdot} + \cdot\text{H} = \text{H}^{\cdot}\text{O}^{\cdot}\text{H} = \text{H-O-H} = \text{H}_2\text{O} \]
Key Distinction

**Covalent Compounds Are Molecules**

**Ionic compounds do not have molecules** (solid or liquid)

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Polyatomic Ions

**Common Anions**
- hydroxide $\text{OH}^-$
- sulfate $\text{SO}_4^{2-}$
- nitrate $\text{NO}_3^-$
- phosphate $\text{PO}_4^{3-}$
- carbonate $\text{CO}_3^{2-}$
- bicarbonate $\text{HCO}_3^-$
- dichromate $\text{Cr}_2\text{O}_7^{2-}$
- perchlorate $\text{ClO}_4^-$
- permanganate $\text{MnO}_4^-$
- acetate $\text{CH}_3\text{CO}_2^-$

**Common Cations**
- ammonium $\text{NH}_4^+$
- hydronium $\text{H}_3\text{O}^+$
- and metals
  - Fe$^{2+}$ iron (II) or ferric
  - Fe$^{3+}$ iron (III) or ferrous
  - Cu$^+$ copper (I) or cupric
  - Cu$^{2+}$ copper (II) or cuprous
Chemical Formulas

**EMPirical Formula** shows the *relative* number of atoms in a compound; derives from the masses of the component elements - elemental analysis

| Acetic acid | CH$_2$O |

**MOLECULAR Formula** shows the *actual* number of atoms in a compound

| Acetic acid | C$_2$H$_4$O$_2$ or (CH$_3$CO$_2$H) |

(extended)

Chemical Formulas: Structural

**Structural Formula** is the most comprehensive representation of a compound, defines completely the number of atoms and their connectivity

Acetic acid, C$_2$H$_4$O$_2$ (CH$_3$CO$_2$H):
Chemical Formulas:
Molecular

\[(NH_4)_2HPO_4 = N_2H_9PO_4\]

\[Ca_3(PO_4)_2 = Ca_3P_2O_8\]

\[Ce(NH_4)_2(NO_3)_6 = \]
Chemical Formulas:
Molecular

\[
\text{(NH}_4\text{)}_2\text{HPO}_4 = \text{N}_2\text{H}_9\text{PO}_4 \\
\text{Ca}_3\text{(PO}_4\text{)}_2 = \text{Ca}_3\text{P}_2\text{O}_8 \\
\text{Ce(\text{NH}_4\text{)}_2\text{(NO}_3\text{)}_6 } = \text{CeN}_8\text{H}_8\text{O}_{18}
\]

Some Nomenclature

- *In ionic compounds, the cation goes first, the anion follows*
  - i.e. ammonium phosphate \((\text{NH}_4^+)_3\text{PO}_4^{3-}\)

- *Metal cations: the same as the name of the metal*
  - i.e. lithium \(\rightarrow\) lithium chloride \(\text{LiCl}\); lead \(\rightarrow\) lead (II) iodide \(\text{PbI}_2\)

- *Monoatomic anions: root + -ide*
  - i.e. chlorine \(\rightarrow\) lithium chloride; oxygen \(\rightarrow\) titanium oxide \(\text{TiO}_2\)

- *Polyatomic anions: oxoanions with more O root + ate, otherwise root + ite*
  - i.e. sulfate \((\text{SO}_4^{2-})\) sulfite \((\text{SO}_3^{2-})\); nitrate \((\text{NO}_3^-)\) nitrite \((\text{NO}_2^-)\)
Some Nomenclature: Acids

- **Polyatomic anions are formed from acids**
  - anion ends with -ate; acid ends with -ic
  - anion ends with -ite; acid ends with -ous

- NO$_3^-$ nitrate
- HNO$_3$ nitric acid
- SO$_4^{2-}$ sulfate
- H$_2$SO$_4$ sulfuric acid
- PO$_4^{3-}$ phosphate
- H$_3$PO$_4$ phosphoric acid
- SO$_3^{2-}$ sulfite
- H$_2$SO$_3$ sulfurous acid
- CO$_3^{2-}$ carbonate
- H$_2$CO$_3$ carbonic acid

- **Binary acids:**
  - hydrofluoric acid HF
  - hydrochloric acid HCl
  - hydrobromic acid HBr
  - hydroiodic acid HI

Some Nomenclature: Binary Covalent Compounds

- **In the same period, the element on the left side is the first word in the name; if in the same period, the element with the higher period number (lower in the periodic table) goes first**

- **The second element: root + ide**

- **Only if more than one element present in the first word, there is a greek numerical prefix to indicate the number of atoms. The second element usually has a prefix.**
Some Nomenclature: Binary Covalent Compounds

CO \hspace{1cm} \text{carbon monoxide}
CO_2 \hspace{1cm} \text{carbon dioxide}
SO_3 \hspace{1cm} \text{sulfur trioxide}
S_2Cl_2 \hspace{1cm} \text{disulfur dichloride}
Cl_2O_7 \hspace{1cm} \text{dichlorine heptaoxide}
N_2O_4 \hspace{1cm} \text{dinitrogen tetraoxide}
N_2O \hspace{1cm} \text{dinitrogen oxide}

Alkanes: page 71

How to predict the composition of ionic compounds from names

*The charges must be balanced!*
Net charge is zero

Example: *aluminum hydroxide*
How to predict the composition of ionic compounds

*The charges must be balanced!*

Net charge is zero

Example: *aluminum hydroxide*

Aluminum is $\text{Al}^{3+}$  
Hydroxide is $\text{OH}^-$  
$\text{Al(OH)}_3$

$\text{AlOH}_3$ is incorrect

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How to predict the composition of ionic compounds

*The charges must be balanced!*

Net charge is zero

Example: *iron (III) [ferric] oxide*
How to predict the composition of ionic compounds

*The charges must be balanced!*

Net charge is zero

Example: *iron (III) [ferric] oxide*

Iron (III) is Fe\(^{3+}\)
oxide is O\(^{2-}\)
balance: \(\text{Fe}_2\text{O}_3\)

\(\text{Fe}_2(\text{O})_3\) is incorrect

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How to predict the composition of ionic compounds

*The charges must be balanced!*

Net charge is zero

Example: *zinc carbonate*
How to predict the composition of ionic compounds

*The charges must be balanced!*

Net charge is zero

Example: **zinc carbonate**

Zinc is Zn\(^{2+}\)

carbonate is CO\(_3\)^{2-}

balance: ZnCO\(_3\)

Zn(CO\(_3\)), Zn(CO\(_3\))^1 are incorrect

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How to predict the composition of ionic compounds

*The charges must be balanced!*

Net charge is zero

Example: **cesium carbonate**

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How to predict the composition of ionic compounds

*The charges must be balanced!*

Net charge is zero

Example: *cesium carbonate*

Cesium is Cs⁺

Carbonate is CO₃²⁻

Balance: $\text{Cs}_2\text{CO}_3$

Cs₂(CO₃), Cs₂(CO₃)$_1$, (Cs)$_2$CO₃ are all incorrect

Molecular Weight (MW or FW)

*molecular mass (weight) = sum of all atomic masses*

Molecular Mass of H₂O is $2 \times 1.008 + 16.00 = 18.02$

Molecular Weight (Mass) is the same thing as *Formula Weight* (Mass)

[ FW ] NaCl
What is the molecular weight of aluminum sulfate?

- Aluminum sulfate is $\text{Al}_2(\text{SO}_4)_3$
- $\text{FW}[\text{SO}_4] = 32.07 + 4 \times 16.00 = 96.07$
- $\text{FW}[\text{Al}_2(\text{SO}_4)_3] = 2 \times 26.98 + 3 \times 96.07 = 342.17$
Molecular Weight (MW)

What is the molecular weight of aluminum sulfate?

• Aluminum sulfate is $\text{Al}_2(\text{SO}_4)_3$

• $\text{Al}_2(\text{SO}_4)_3 = \text{Al}_2\text{S}_3\text{O}_{12}$

• $\text{FW}[\text{Al}_2(\text{SO}_4)_3] = 2 \times 26.98 + 3 \times 32.07 + 12 \times 16.00 = 342.17$

Molecular Weight (MW)

What is the molecular weight of copper (II) sulfate pentahydrate?

• $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$

• $\text{FW}[\text{CuSO}_4 \cdot 5\text{H}_2\text{O}] = 63.55 + 96.07 + 5 \times 18.02 = 249.72$
Mixtures

- **heterogeneous**
  - has boundaries between component (phase separation)

- **homogeneous**
  - no boundaries between component (phase separation)
  - solutions: liquid mixtures
  - aqueous solutions: the solvent is water

Mixtures: Separation

- filtration
- crystallization
- distillation
- extraction
- chromatography
Mixtures: Separation

• filtration (heterogeneous)
  based on the difference in the state of matter (solid/liquid)

Mixtures: Separation

• crystallization (heterogeneous)
  based on the difference in solubility
Mixtures: Separation

- **distillation** (homogeneous)
  
  based on the difference in volatility / boiling point

This simplified drawing shows many of a refinery’s most important processes.
Mixtures: Separation

- extraction (homogeneous) based on the difference in solubility (organic/aqueous)

Mixtures: Separation

- chromatography (homogeneous) based on the difference in solubility (organic/aqueous) and absorbance on immobile phase
Next Time: Stoichiometry