Compounds of Metals
Ionic Bonding and Inorganic Compounds

MODIFIED FROM Dr. Patricia Hill, Millersville University
Compounds of Metals

- **Ores**
  - Hematite
  - Chalcopyrite
  - Bauxite

- **Corrosion**
  - Rust = iron oxide = $\text{Fe}_2\text{O}_3$
  - Alumina = aluminum oxide = $\text{Al}_2\text{O}_3$
  - Tarnish = silver sulfide = $\text{Ag}_2\text{S}$
  - Darkened white paint = Lead sulfide = $\text{PbS}$

- **Metallic salts**
  - Sodium chloride = NaCl
  - Copper chloride = CuCl$_2$ and CuCl
Bohr Model of the Atom

- **Planetary model** of electron location
- **Energy shells** contain maximum number of electrons — $2n^2$

- Electron shells
  - Shell 1 = 2e
  - Shell 2 = 8e
  - Shell 3 = 18e
  - Shell 4 = 32e

Nucleus
(p$^+$ and n$^0$)
Bohr Diagrams of Atoms

- Need to know
  - Symbol of element
  - Number of \( p^+, n^0, \) and \( e^- \)
  - How many electrons in each shell

- Aluminum
  - \( \text{Al} \) (\( Z = 13, A = 27 \))
What Are Valence Electrons?

Valence electrons in outermost shell

Core electrons (inner shells)

Nucleus
Finding Valence Electrons

Look at the Periodic Table

For Main Group Elements (A)

\( \text{Group Number} = \text{number of valence electrons} \)
Importance of Valence Electrons

- **Valence** electrons — in outermost shell
  - Account for chemical properties and reactivity of elements
  - Allow atoms to form chemical bonds
  - Group number of A elements
Lewis Dot Structures of Elements

Hydrogen
H·

Aluminum
· Ål·

- Show only the valence electrons

- Need to know
  Symbol of element
  Number of valence electrons
Lewis Dot Structures

- Draw the correct dot structures for
  Sodium
  Calcium
  Carbon
  Chlorine
  Oxygen
  Nitrogen
Chemical Bonding

- Holds all matter together
- The key players are

VALENCE electrons
What Are Chemical Bonds?

- 5 Types of chemical bonds hold all matter together
  - *Covalent Bonding*
  - *Ionic Bonding*
  - *Metallic Bonding*
  - *Hydrogen Bonding*
  - *Van der Waals Forces*

Strongest  

Weakest
The Top Three Types of Bonds

- **covalent bonds** = sharing of electrons
- **ionic bonds** = exchange of electrons
- **metallic bonds** = delocalization of electrons
Metallic Bonding

- Metals have 1, 2, or 3 valence electrons
- Valence electrons shared by all metal atoms
- Metal cations arranged in regular array

“sea of electrons” surround metal cations
Delocalized Electrons in Metals

- Provide metallic properties
  - conduction and luster
  - density and strength
  - crystalline structure
  - ability to easily form alloys

Grains in steel
Metallic Salts—Ionic Bonding

- **Octet Rule** — atoms prefer to have a filled valence shell containing 8 electrons (except He)
- To obtain an octet atoms **lose, gain or share electrons**
- Ionic bonds result when one element loses electrons and the other element gains electrons
Ionic Bond

- **Cations** and **anions** are formed and held together by strong (+) and (-) charges.
Ionic Bonding

- Results in **IONIC COMPOUNDS**
- Basic unit formed is called a **FORMULA**
- Ionic compounds formed between **Metals** - Groups I, II, III
  **Nonmetals** - Groups V, VI, VII
Formation of **Positive Ions**

- Metal elements in Groups 1, 2 and 3A can easily lose 1, 2 or 3 valence electrons to obtain an “octet”

  \[
  \begin{align*}
  \text{Na} & \rightarrow \text{Na}^+ + \quad \text{(1 e-)} \\
  \text{Mg} & \rightarrow \text{Mg}^{+2} + \quad \text{(2e-)} \\
  \text{Al} & \rightarrow \text{Al}^{+3} + \quad \text{(3e-)}
  \end{align*}
  \]

- Results in **cation** formation

- Called an **oxidation** reaction (**OIL**)
Formation of Cations

Na$^-$ \rightarrow Na^+ + \cdot (1 \text{ e}^-)

11 +
11 -
0 charge

Octet in shell 2

One valence electron in shell 3

11 +
10 -
+1 charge
Formation of **Negative Ions**

- Nonmetal elements in groups VA, VIA, and VIIA can easily gain 1, 2, or 3 electrons to obtain an “octet”

  \[
  \begin{align*}
  \text{N}^- + 3e^- &\rightarrow \text{N}^{3-} \\
  \text{O}^- + 2e^- &\rightarrow \text{O}^{2-} \\
  \text{Cl}^- + 1e^- &\rightarrow \text{Cl}^{-1}
  \end{align*}
  \]

- result in **ANION** formation - **REDUCTION** (RIG)
Formation of Anions

\[ \text{N}^+ + 3e^- \rightarrow \text{N}^{3-} \]

- **7p⁺**
- **7n**

5 valence electrons in shell 2

- **7 +**
- **7 -**
- **0 charge**

+ 3 electrons

Octet of electrons in shell 2

- **7 +**
- **10 -**
- **-3 charge**
Ionic Bonds — Ionic Compounds

Ionic compounds

- Crystalline solids with high mp
- Usually water soluble
- Electrolytes (conduct electricity)

Electrostatic attraction = ionic bond
Do Ions Really Exist?

pure $\text{H}_2\text{O}$ = 

$\text{H}_2\text{O} + \text{NaCl}$ = 

$\text{H}_2\text{O} + \text{Sugar}$ = 

Tap water = 

Conductivity tester
Binary Compounds

- composed of only 2 different elements
- may be ionic or covalent compounds

IONICS = a metallic element is usually present

COVALENTS = contain only nonmetallic elements
Ionic or Covalent?

- HCl
- NaCl
- PCl$_5$
- Cu(OH)$_2$
- NH$_3$
- CH$_3$COOH
- Ag$_2$S

Metal + Nonmetal = Ionic
Binary Ionic Compounds

- **Writing correct names from formulas**
  1. Metal ions get its element name and is put first
  2. Nonmetal ion is named second and the ending of its name is changed to —IDE

NaCl  Sodium chlorIDE
CaCl₂  Calcium chlorIDE
AlCl₃  Aluminum chlorIDE
Binary Covalent Compounds

- **Writing correct names from formulas**
  1. First element gets its elemental name
  2. The ending of the name of the second element is changed to —IDE
  3. If *numerical subscripts* are present
     • use *prefixes* to indicate how many atoms are present

<table>
<thead>
<tr>
<th>Formula</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCl</td>
<td>Hydrogen chlorIDE</td>
</tr>
<tr>
<td>H₂S</td>
<td>Dihydrogen sulfIDE</td>
</tr>
<tr>
<td>CCl₄</td>
<td>Carbon tetrachlorIDE</td>
</tr>
</tbody>
</table>
Comparing Ionics & Covalents

- **Binary Ionics** (metallic element)
  - NaCl  Sodium chlorIDE
  - CaCl$_2$  Calcium chlorIDE
  - AlCl$_3$  Aluminum chlorIDE

- **Binary Covalents** (no metallic elements)
  - HCl  Hydrogen chlorIDE
  - H$_2$S  Dihydrogen sulfIDE
  - CCl$_4$  Carbon tetrachlorIDE
Binary Ionic Compounds

- **Writing correct formulas**
  1. Metal symbol written first
  2. Nonmetal symbol second
  3. Appropriate subscripts so that amount of (+) equals amount of (-)

\[
\begin{align*}
\text{Na}^{+1} & + \text{Cl}^{-1} \quad \rightarrow \quad \text{NaCl} \\
\text{Ca}^{+2} & + \text{Cl}^{-1} \quad \rightarrow \quad \text{CaCl}_2 \\
\text{Al}^{+3} & + \text{Cl}^{-1} \quad \rightarrow \quad \text{AlCl}_3
\end{align*}
\]
Finding Charges for Cations

Metallic elements form cations by losing electrons.

- Group 1A (Na, K, Rb, Cs, Fr) forms a 1+ charge.
- Group 2A (Be, Mg, Ca, Sr, Ba) forms a 2+ charge.
- Group 3A (Al, Ga, In, Tl) forms a 3+ charge.

(The charge is the same as the group number.)

![Periodic Table](http://pubs.acs.org/cen/80th/elements.html)
Finding Charges for Anions

Nonmetallic elements form anions by gaining electrons, which is calculated as the group number of the element minus 8:

- Group 5A: $5A = 5 - 8 = -3$
- Group 6A: $6A = 6 - 8 = -2$
- Group 7A: $7A = 7 - 8 = -1$

Periodic Table of the Elements 2006

See “It’s Elemental: The Periodic Table” http://pubs.acs.org/cen/80th/elements.html

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Ions of Transition Metals

- can form several different charged ions
- important ones to know
  - Fe
  - Fe$^{+2}$ and Fe$^{+3}$
  - Cu
  - Cu$^{+1}$ and Cu$^{+2}$
  - Sn
  - Sn$^{+2}$ and Sn$^{+4}$
  - Ag = +1
  - Cr, Co, Ni, Zn, Cd, Hg, Pb = +2
The “Cross-over” Method

- Quick way to write formulas for ionic compounds

$$\text{Al}^{+3} \quad \text{O}^{-2}$$

$$\text{Al}_2\text{O}_3$$

- The value of the charge on one ion becomes the subscript for other ion
Obtaining Metals from Ores

Never occur “Free”

- Lithium
- Potassium
- Barium
- Strontium
- Calcium
- Sodium
- Magnesium
- Beryllium
- Aluminum
- Manganese
- Zinc
- Chromium

Rarely found “Free”

- Iron
- Cadmium
- Cobalt
- Nickel
- Tin
- Lead
- HYDROGEN

Often found “Free”

- Copper
- Mercury
- Silver
- Platinum
- Gold
- Arsenic
The **Redox Cycle**

Hematite (iron ore) = Fe$_2$O$_3$ + e$^-$

Rust = Fe$_2$O$_3$ — e$^-$

**Oxidation (OIL)**

**Reduction (RIG)**
Spontaneous Redox Reaction

\[
\text{Cu} + \text{AgNO}_3 \rightarrow ???
\]

Copper metal \(\rightarrow\) Silver nitrate

Copper metal disappears and silver metal appears.

Copper metal loses electrons to form copper cations (oxidation).

silver ions gain electrons to form silver metal (reduction).
Obtaining Metals from Ores

- Iron occurs most frequently as Fe$_2$O$_3$ and not as “native iron”
- Ores are “oxidized metals”
- Fe$^{+3}$ is “oxidized iron” — it has...

  lost electrons
  gained oxygen

  $4 \text{Fe} + 3 \text{O}_2 \rightarrow 2 \text{Fe}_2\text{O}_3$
Oxidation-Reduction Reactions

- To obtain iron metal the Fe must be forced to...

Hematite (iron ore) = Fe$_2$O$_3$

\[
\text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2
\]

iron compound
free iron

gain electrons
lose oxygen
Copper from Chalcopyrite

CuFeS$_2$
Copper
Concentrate

FeSiO$_3$
CaSiO$_3$

SO$_2$

CuFeS$_2$
Copper Concentrate

Oxygen

Slag

Matte

Cu
Redox and Metallurgy

- **Refining** of metals — supplying electrons to produce “reduced metals”
  - iron from Fe$_2$O$_3$ (hematite)
  - aluminum from Al$_2$O$_3$ (bauxite)
  - copper from CuS, Cu$_2$O, CuFeS$_2$

- **Electrolysis and Electroplating**
  - use of electricity to produce oxidation-reduction reactions with metals
Chemical Equations

- Formulas for all elements and compounds involved in the reaction
- How many atoms or molecules of things are present at beginning and at the end
- Total number and types of atoms must be equal on left and right of arrow (balanced)
Balanced Chemical Equations

- Matter cannot be created or destroyed!
- Total number and types of atoms must be the same on both sides of the arrows
- The arrangement and combinations of atoms are different on each side of the arrow

Fe₂O₃ + 3CO → 2Fe + 3CO₂
Balancing Simple Equations

\[ \text{H}_2 + \text{O}_2 \rightarrow \text{H}_2\text{O} \]

Count up atoms on each side of arrow.

\[
\begin{array}{c|c|c}
\text{H} & 2 & \text{H} & 2 \\
\text{O} & 2 & \text{O} & 1 \\
\end{array}
\]

Balance unbalanced elements by placing small whole number coefficients in front of formulas. Recount.

\[ 2 \text{H}_2 + \text{O}_2 \rightarrow 2 \text{H}_2\text{O} \]

\[
\begin{array}{c|c|c}
\text{H} & 4 & \text{H} & 4 \\
\text{O} & 2 & \text{O} & 2 \\
\end{array}
\]
Balancing Simple Equations

\[
\begin{align*}
\text{Al} &+ \text{Cl}_2 \rightarrow \text{AlCl}_3 \\
\text{Al} &\quad 1 \quad \text{Al} &\quad 1 \\
\text{Cl} &\quad 2 \quad \text{Cl} &\quad 3 \\
\text{Al} &+ 3\text{Cl}_2 \rightarrow 2\text{AlCl}_3 \\
\text{Cl} &\quad 6 \quad \text{Cl} &\quad 6 \\
\text{Al} &\quad 1 \quad \text{Al} &\quad 2 \\
2\text{Al} &+ 3\text{Cl}_2 \rightarrow 2\text{AlCl}_3 \\
\text{Al} &\quad 2 \quad \text{Al} &\quad 2 \\
\text{Cl} &\quad 6 \quad \text{Cl} &\quad 6
\end{align*}
\]
Are these equations balanced?

\[ \text{N}_2 + \text{O}_2 \rightarrow \text{NO} \]

\[ 2 \text{HgO} \rightarrow \text{Hg} + \text{O}_2 \]

\[ \text{Al} + \text{Cl}_2 \rightarrow \text{AlCl}_3 \]

\[ 2 \text{Cu}_2\text{O} + \text{O}_2 \rightarrow 4 \text{CuO} \]
Large-Scale Reactions

- Impossible to measure out atoms and molecules.
- Chemists use **MOLES** instead of molecules.

Moles help us relate:

- Number of atoms, molecules, ions, electrons
  - Hard to see or count
- Grams of elements or compounds
  - Easy to see and measure
Molar Quantities in Equations

\[ \text{Fe}_2\text{O}_3 + 3\text{CO} \rightarrow 2\text{Fe} + 3\text{CO}_2 \]

1 mole of iron(III) oxide
plus
3 moles of carbon monoxide
produce
2 moles of elemental iron
and
3 moles of carbon dioxide
What is a Mole?

- 1 mole = $6.02 \times 10^{23}$ things
- The “things” can be
  - Atoms
  - Molecules
  - Ions
  - Electrons
Practically a mole is...

- 1 mole of an element = atomic weight of the element in grams
- 1 mole of a compound = sum of atomic weights of all elements in the compound in grams

\[ 12 \text{ g C} = 6.02 \times 10^{23} \text{ atoms of carbon} \]

\[ 18 \text{ g H}_2\text{O} = 6.02 \times 10^{23} \text{ molecules of water} \]