Atomic Structure

1. Historical View - Dalton's Atomic Theory

Based on empirical observations, formulated as Laws of:

*Conservation of Mass*
*Definite Proportions*
*Multiple Proportions*

Summary of Dalton's theory:

- matter is composed of small particles called atoms
- in chemical reactions atoms are indestructible
- atoms of different elements have different masses
- atoms of the same and/or different elements combine to form new substances (i.e., compounds)
- in a given compound, the constituent atoms are always combined in the same fixed numerical ratio

2. "Modern" View

atom consists of: central **nucleus** containing **protons** (+) and **neutrons**
with outer shells of **electrons** (-)

most of an atom's mass is in the nucleus -- relative masses:

- neutron = proton = 1 amu
- electron ≈ 10^{-4} amu  (amu = atomic mass unit = 1.66 x 10^{-24} g)
3. Atomic Masses and Isotopes

\[ Z = \text{atomic number of an element} = \# \text{ protons in nucleus} \]

e.g., carbon is atomic number 6 -- all carbon atoms have 6 protons

\[ A = \text{mass number} \ (\text{often omitted}) = \# \text{ protons} + \# \text{ neutrons} \]

\[ Y = \text{charge} \ (\text{on an ion}) = \# \text{ protons} - \# \text{ electrons} \]

isotopes - atoms of the same element with different mass numbers

e.g., natural carbon has 2 isotopes (2 types of C atoms):

<table>
<thead>
<tr>
<th>Isotope</th>
<th>symbol</th>
<th>relative abundance</th>
<th>protons</th>
<th>neutrons</th>
<th>mass number</th>
</tr>
</thead>
<tbody>
<tr>
<td>carbon-12</td>
<td>$^{12}\text{C}$</td>
<td>99%</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>carbon-13</td>
<td>$^{13}\text{C}$</td>
<td>1%</td>
<td>6</td>
<td>7</td>
<td>13</td>
</tr>
</tbody>
</table>

atomic mass (atomic weight) of an element is based on the $^{12}\text{C}$ scale:

1 atom of $^{12}\text{C}$ is defined as exactly 12 amu

since most elements are actually mixtures of isotopes, the atomic mass (or weight) is really an "average" atomic mass

e.g., atomic mass of chlorine, Cl, is 35.4527 amu

\[ ^{35}\text{Cl} \quad 75.77\% \quad 34.9689 \text{ amu} \]
\[ ^{37}\text{Cl} \quad 24.23\% \quad 36.9659 \text{ amu} \]

"weighted average"

\[(0.7577 \times 34.9689) + (0.2423 \times 36.9659) = 35.4527 \ (= 35.45)\]

Normally, chemists are concerned with such "average" atomic masses
The Mole Concept and Molar Mass

1. Avogadro's Number -- The Chemist's "Dozen"

\[ N_0 = \text{number of atoms in } \textit{exactly} \text{ 12 grams of carbon-12} \]
\[ = 6.022 \times 10^{23} \text{ "things"} \quad \{\text{a very large number} \} \]

this is a conversion factor, just like 12 things per dozen, e.g.:

mass of one atom of carbon-12 = \( \frac{(12 \text{ g})}{(6.022 \times 10^{23} \text{ atoms})} \)
\[ = 1.99 \times 10^{-23} \text{ g/atom} \]

2. The Mole -- How Chemists "Count"

\textit{One Mole of a substance contains an Avogadro's Number of formula units}

1 mole = \( 6.022 \times 10^{23} \) formula units

e.g., 1 mole of iron contains \( 6.022 \times 10^{23} \text{ Fe atoms} \)

3. Molar Mass

\textit{Molar Mass = the mass (in grams) of one mole of a substance}

Since 12 grams of \(^{12}\text{C}\) is defined as 1 mole of \(^{12}\text{C}\) and the atomic masses of other elements are defined relative to that, then…..

the molar mass of an element = its atomic mass in grams/mole

\textit{\textit{e.g.}, from the periodic table, the "atomic mass" of Al is 26.98 What does this mean?}

- mass of one Al atom = 26.98 amu
- molar mass of Al = 26.98 g/mole (mass of one mole of Al)
The Periodic Table

1. General arrangement - increasing atomic number within:

   **groups**: vertical columns (also called families)

   **periods**: horizontal rows

2. Terminology - parts of the periodic table

   - **representative elements** .......... the longer columns (the "A" groups)
   - **transition elements** ............... shorter, central columns ("B" groups)
   - **alkali metals** ....................... group IA (1): Li, Na, K, ...
   - **alkaline earth metals** ............ group IIA (2): Be, Mg, Ca, ...
   - **halogens** .......................... group VIIA (17): F, Cl, Br, ...
   - **noble gases** ...................... group 0 (18): He, Ne, Ar, ...
   - **lanthanide elements** .............. # 58 - 71 (1st row at bottom)
   - **actinide elements** ............... # 90 - 103 (2nd row at bottom)

3. Types of elements - by physical properties

   - **metals**: shinny, malleable, ductile solids with high mp and bp
     good electrical conductors

   - **nonmetals**: gases, liquids, or low-melting solids
     non-conductors of electricity

   - **diatomic elements**: H₂, O₂, N₂, F₂, Cl₂, Br₂, I₂

   - **metalloids**: intermediate properties, often semiconductors (e.g., Si)
Ions and the Periodic Table

1. Elements combine to form compounds -- two general types

**Molecular Compounds** -- more later in Chapter 3!
atoms linked together by "chemical bonds" in discrete electrically neutral particles called *molecules*
e.g., $\text{H}_2\text{O}$  $\text{CO}_2$  $\text{PCl}_3$  $\text{C}_{12}\text{H}_{22}\text{O}_{11}$

**Ionic Compounds**
result from transfer of one or more electrons from one atom to another to yield oppositely-charged particles called *ions*

cation = positive ion  anion = negative ion

there are not discrete molecules -- the ions are held together by electrostatic forces in a regular, 3-dimensional pattern called a *crystalline lattice*
e.g., LiF  lithium fluoride

$$\text{Li}^- + \text{F}^- \rightarrow \text{Li}^+ + \text{F}^-$$  LiF

MgCl$_2$  magnesium chloride

$$\text{Mg} + 2\text{Cl}^- \rightarrow \text{Mg}^{2+} + 2\text{Cl}^-$$  MgCl$_2$
2. Relationship to Periodic Table

General trends (Figure 2.14)

**Ionic compounds** usually involve *metals and nonmetals*

- group IA (1) +1 cations \( \text{Li}^+, \text{Na}^+, \text{K}^+, \ldots \)
- group IIA (2) +2 cations \( \text{Be}^{2+}, \text{Mg}^{2+}, \text{Ca}^{2+}, \ldots \)

other metals may form more than one cation, e.g.:

- \( \text{Fe}^{2+} \) and \( \text{Fe}^{3+} \)
- \( \text{Sn}^{2+} \) and \( \text{Sn}^{4+} \)

- group VIA (16) -2 anions \( \text{O}^{2-}, \text{S}^{2-}, \text{Se}^{2-}, \ldots \)
- group VIIA (17) -1 anions \( \text{F}^-, \text{Cl}^-, \text{Br}^-, \ldots \)

**Molecular compounds** usually result from the combination of two *nonmetals and/or metalloids*

- e.g., \( \text{PH}_3 \) \( \text{AsF}_5 \) \( \text{HBr} \)

some nonmetallic elements actually exist as molecular compounds

- e.g., the diatomics (\( \text{H}_2 \), \( \text{O}_2 \), \( \text{N}_2 \), etc. as listed before)
  - also: \( \text{P}_4 \), \( \text{As}_4 \), \( \text{S}_8 \), \( \text{Se}_8 \)