Chapter 2
Atoms, Molecules, and Ions

An STM image of tiny wires, just 10 atoms thick and laid down on a surface of silicon.

Nickel atoms – STM

Law of Definite Proportions
- Lavoisier and Proust discovered that all samples of a single substance exist in the same ratio by mass.
  - H₂O: 1 part H, 8 parts O, by mass
  - CO₂: 1 part C, 2.7 parts O, by mass
- Different samples of a pure chemical substance always contain the same proportion of elements by mass.

Dalton's Atomic Theory
- Dalton's Theory:
  - Elements are made up of tiny particles called atoms.
  - Each element is characterized by the mass of its atoms. Atoms of the same element have the same mass, but atoms of different elements have different masses.
  - Chemical combination of elements to make different substances occurs when atoms join together in small, whole-number ratios.
  - Chemical reactions only rearrange the way that atoms are combined; the atoms themselves don't change.

Law of Multiple Proportions
- Elements can combine in different ways to form different substances, whose mass ratios are small, whole-number multiples of each other.

The Structure of the Atom
- Late-1880's, J.J. Thomson experimented with cathode ray tubes, electricity, and magnetism to learn more about atoms' structures. He discovered the presence of negatively charged particles, now called electrons.
Cathode Ray Tubes

- Why does the beam bend?

Oil Drop Experiment

- In early 1900's, Millikan used an oil drop experiment to determine the charge of an electron (1.6 x 10^-19 C).

Oil Drop

Nuclear Atom

- In 1911, Rutherford, tried to determine the arrangement of negative electrons and positive nucleus in an atom.
- Gold foil experiment: Law of Electrostatic Attraction; positive alpha particles.

Rutherford’s Experiment

History Overview

- Boyle: first to study chemistry
- Priestley & Lavoisier: Conservation of Mass
- Proust: Law of Definite Proportions
- Dalton: 4 postulates — Theory of matter
  - Law of Multiple Proportions
- Thomson: presence of electrons; plum pudding
- Millikan: charge of an electron
- Rutherford: presence of small, positive nucleus

Relative Sizes

- Nucleus is to an atom what a pea is to a stadium

Atomic Structure

- The protons and neutrons in the nucleus take up very little volume but contain essentially all the atom’s mass.
- A number of electrons equal to the number of protons move about the nucleus and account for most of the atom’s volume.

<table>
<thead>
<tr>
<th>Particle</th>
<th>Mass (amu)</th>
<th>Charge (e)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>9.109 383 x 10^-28</td>
<td>-1.602 176 x 10^-19</td>
</tr>
<tr>
<td>Proton</td>
<td>1.672 623 x 10^-27</td>
<td>+1</td>
</tr>
<tr>
<td>Neutron</td>
<td>1.674 927 x 10^-27</td>
<td>0</td>
</tr>
</tbody>
</table>

* The atomic mass unit (amu) is defined in Section 2.8.
Atomic Numbers

- What makes one atom different from another?
  - Their number of protons, aka their atomic number (Z) (subscript)
- Where can we find this information on the periodic table?
  - H = 1 proton, He = 2 protons, Li = 3 protons
- Number of neutrons in nucleus also influences an atom’s mass and, therefore, its behavior.
  - Mass number (A) is sum of protons & neutrons (superscript).
- Most hydrogen: Z = 1, A = 1. How many neutrons?
- Most helium: Z = 2, A = 4. How many neutrons?
- How many protons and neutrons in 54\text{Cr} (chromium-54)?

Worked Ex. 2.4; Problems 2.4 – 2.6

Atomic #, Mass #, and Isotopes: Carbon

- How many of each particle in these atoms (protons, electrons, neutrons)?
  - $^1\text{H}^+$, $^3\text{H}$
  - $^{12}\text{C}$, $^{14}\text{C}^+$
  - $^{15}\text{O}$, $^{16}\text{O}^2$-
  - $^{14}\text{N}$, $^{15}\text{N}^3$-
  - $^{238}\text{U}$, $^{234}\text{U}$

Atomic Mass

- Atomic mass unit: exactly one-twelfth the mass of a carbon-12 atom.
- Mass of 1 $^{12}\text{C}$ atom = 12 amu (exactly)
- $6.022 \times 10^{23}$ amu = 1 g
- Atomic mass on periodic table is weighted average of abundance of an atom’s isotopes.
  - $^{12}\text{C} = 12$ amu: 98.89%
  - $^{13}\text{C} = 13.0034$ amu: 1.11%
- What is the mass of Cu if 69.09% has a mass of 62.93 amu and 30.91% has a mass of 64.94 amu?
- Worked Ex. 2.5; Problems 2.7, 2.8

Terminology

- Atom: individual atom (one sphere in an image)
- Molecule: substance made up of two or more atoms
- Compound: substance made up of two or more different atoms or ions
- Pure substance: all atoms, compounds, or molecules are the same in a sample
- Mixture: blends of two or more different substances
  - Homogeneous: uniform throughout (seawater)
  - Heterogeneous: not uniform (water and oil)

Classifications of Matter

- Describe each picture below using the terms
  - mixture or pure substance
  - atom, element, molecule, and/or compound
Classify

- Mixture or Pure Substance
- Atom, element, molecule, and/or compound

- How many boxes are mixtures?
- How many boxes contain only compounds?
- How many boxes contain elements?

Answers

- A1: pure substance; molecules of a compound
- A2: pure; molecules of a compound
- A3: pure; molecules of a compound
- B1: pure; molecules of a compound
- B2: pure; molecules of a compound
- B3: mixture; molecules of elements
- C1: pure; atoms of an element
- C2: mixture; molecules of compounds
- C3: mixture; atoms and molecules of elements
- D1: pure; atoms of an element
- D2: pure; molecules of a compound
- D3: mixture; molecules of compound, atoms of element

Classifications of Matter

- How would you classify the following?
  - Air
  - Distilled water
  - Ice
  - Ice Cream
  - Rocks
  - Gold

Covalent Chemical Bonds

- Diatomic molecules:
  - H₂, N₂, F₂, O₂, I₂, Cl₂, Br₂
- Covalent bonds: form when atoms share electrons, typically between nonmetals

Covalent Compounds

- Write formulas for the following structures:
  - Ethanol
  - Glucose

- Worked Ex. 2.6; Key Concept 2.7, 2.11, 2.12; Problem 2.9, 2.10

Ionic Chemical Bonds

- Ionic bonds form when atoms transfer electrons, typically between metal and nonmetal
- Ions are atoms or groups of atoms that have a positive or negative charge (have gained or lost electrons)
  - Anions have gained one or more electrons; since electrons are negative, anions have negative charges
  - Cations have lost one or more electrons; cations have positive charges
- NaCl (salt); NaOH (in bleach)
Molecules, Ions, and Chemical Bonds

- Which side of the periodic table gains electrons? Loses electrons?
  - Metals tend to lose electrons, have a positive charge (cation)
  - Nonmetals tend to gain electrons, have a negative charge (anion)
- Na → Na\(^{1+}\)
- Cl → Cl\(^{-}\)
- Mg → Mg\(^{2+}\)
- S → S\(^{2-}\)

What do Ionic & Covalent Compounds Look Like?

Covalent vs Ionic Bonding

- Classify the following types of bonds as covalent or ionic:
  - NO\(_2\)
  - CaO
  - KBr
  - CO\(_2\)
  - KrF\(_2\)
  - CuCl\(_2\)
- Worked Ex. 2.8; Problems 2.13, Key Concept 2.14

Formulas of Ionic Compounds

- Fluorite: CaF\(_2\)
- How are these ions bonded?
- Which picture below could be CaF\(_2\)?
- Why isn’t the structure Ca – F – F?

Green = metal, blue = nonmetal