Atoms, Elements, and the Periodic Table (Chapter 2)

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 $\approx$ proton $\approx$ 1 amu

electron $\approx$ 10^{-4} amu (amu = atomic mass unit = 1.66×10^{-24} g)

3. Atomic Masses and Isotopes

$$^{A}_{Z}X^{Y}$$

Z = ***atomic number*** of an element = # protons in nucleus

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

A = ***mass number*** (often omitted) = # protons + # neutrons

Y = ***charge*** (on an ion) = # protons - # electrons

isotopes - atoms of the same element with different mass numbers

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

Isotope	symbol	relative abundance	protons	neutrons	mass number
carbon-12	^{12}C	99%	6	6	12
carbon-13	^{13}C	1%	6	7	13

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

1 atom of ^{12}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 <u>35.4527</u> amu

^{35}Cl 75.77% 34.9689 amu

^{37}Cl 24.23% 36.9659 amu

"weighted average"

(0.7577 x 34.9689) + (0.2423 x 36.9659) = <u>35.4527</u> (≈ 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_o = number of atoms in *exactly* 12 grams of carbon-12

= **6.022×10^{23}** "things" {a *very* large number ! }

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

mass of one atom of carbon-12 = (12 g) / (6.022×10^{23} atoms)

= 1.99×10^{-23} g/atom

2. The Mole -- How Chemists "Count"

One Mole of a substance contains an Avogadro's Number of formula units

1 mole = 6.022×10^{23} formula units

e.g., 1 mole of iron contains 6.022×10^{23} Fe atoms

3. Molar Mass

Molar Mass = the mass (in grams) of one mole of a substance

Since 12 grams of ^{12}C is defined as 1 mole of ^{12}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

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: H_2, O_2, N_2, F_2, Cl_2, Br_2, I_2

   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*

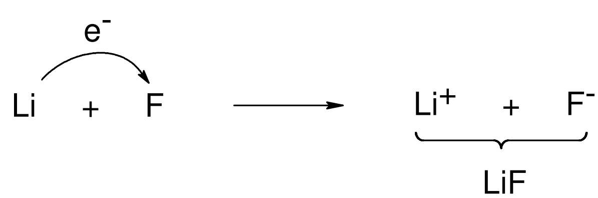
e.g., H_2O CO_2 PCl_3 $C_{12}H_{22}O_{11}$

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

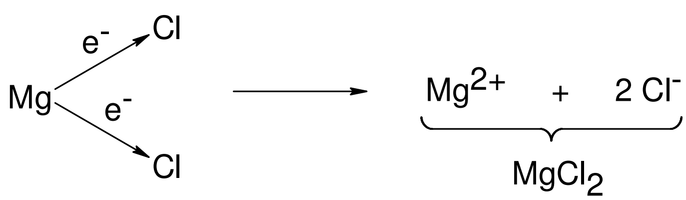
cation = positive ion ***anion*** = negative ion

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



$MgCl_2$ magnesium chloride



2. Relationship to Periodic Table

General trends (Figure 2.14)

Ionic compounds usually involve *metals* and *nonmetals*

group IA (1)	+1 cations	Li^+, Na^+, K^+, ...
group IIA (2)	+2 cations	Be^{2+}, Mg^{2+}, Ca^{2+}, ...

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

Fe^{2+} and Fe^{3+} Sn^{2+} and Sn^{4+}

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

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

e.g., PH_3 AsF_5 HBr

some nonmetallic elements actually exist as molecular compounds

e.g., the diatomics (H_2, O_2, N_2, etc. as listed before)
also: P_4, As_4, S_8, Se_8