Module 2 – Atomic Structure & Chemical Bonding: Look at all the pretty fireworks.

Early Atoms
- Dalton’s Atom
  - Small, hard, spherical, indestructible, and indivisible
  - All atoms of an element are alike
- Nuclear atom
  - Protons, neutrons in central, tiny nucleus
  - Electrons occupy electron cloud

Atomic Size
- Extremely small; H atom diameter = 1x10⁻⁸ cm; 1 million in width of pencil lead
- Imaged by powerful instruments: scanning tunneling electron microscope
  - Can “see” atoms
Atomic Structure

- Atoms have electrical properties
- Subatomic particles observed
  - Electron, very small mass, -1 charge
  - Proton, mass 1 u (atomic mass unit), +1 charge, mass of H atom
  - Neutron, subatomic particle with mass 1 u and no electrical charge
- Atoms are neutral, so no. protons = no. electrons
  - E.g., an oxygen atom (at. no. 8) has 8 protons and 8 electrons

<table>
<thead>
<tr>
<th>Subatomic Particle</th>
<th>Symbol</th>
<th>Mass (u)</th>
<th>Charge</th>
<th>Location in Atom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>p⁺</td>
<td>1</td>
<td>1⁺</td>
<td>Nucleus</td>
</tr>
<tr>
<td>Neutron</td>
<td>n</td>
<td>1</td>
<td>0</td>
<td>Nucleus</td>
</tr>
<tr>
<td>Electron</td>
<td>e⁻</td>
<td>0.000551</td>
<td>1⁻</td>
<td>Outside nucleus</td>
</tr>
</tbody>
</table>

Nuclear Atom

- Rutherford’s Gold Foil Experiment
- Nucleus, small volume, all mass of atom
- Nucleus composed of protons and neutrons
- Electrons occupy bulk of atom’s volume = electron cloud
Atopic number = no. of protons in an atom
- hydrogen has no. 1; its atom has 1 proton

Mass number = mass of an atom in amu = sum of no. of protons plus neutrons
- E.g., mass no. of a carbon atom (6 protons) that has 6 neutrons = 6 + 6 = 12 amu

Q: How many neutrons does an atom of uranium (at. no. 92), that has a mass no. of 238, have?

Nuclear Symbol
Mass no. = no. protons + no. neutrons

Atomic no. = no. protons

Symbol

\[ ^{1}H \]
Isotopes

- Different types of atoms of an element
- Same no. protons, but different no. of neutrons and diff. mass no.
- E.g., carbon exists as C-12, C-13, and C-14.
  - C-12 has a mass no. of 12, it has 6 protons and 6 neutrons.
  - C-13 has a mass no. of 13; it has 6 protons and 7 neutrons.
  - C-14 has a mass no. of 14; it has 6 protons and 8 neutrons

Atomic Mass

- Average mass of atoms of an element
- Includes relative abundance and isotopic masses
Ionization
- An electron leaves an atom
  - Amount of energy is called the ionization energy
- The resulting atom is a positively charged ion, called a cation
  - Charges can be 1+, 2+, or 3+ when 1, 2, or 3 electrons are lost
- If atoms gain electrons they form negatively charged ions called anions
  - Charges can be 1-, 2-, 3- when 1, 2, or 3 electrons are gained

Bohr Model
- Electrons have specific locations, orbits/shells (n), with specific energies
- Electron energy increases from inside to the surface of the atom
- Shells have maximum capacities

<table>
<thead>
<tr>
<th>n</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>72</td>
</tr>
<tr>
<td>7</td>
<td>92</td>
</tr>
</tbody>
</table>

- Energy Emissions from Atoms
  - When an atom is energized by heating or energy bombardment (electron or energy beams), it emits electromagnetic radiation
  - The emission spectrum is characteristic for an element
  - Represent specific energies
Emission of Light
- When an atom is subjected to an energy source (flame, radiation), an electron accepts a specific quantity of energy and jumps to a higher energy level, excitation.
- The excited electron is unstable at the higher energy level (the atom is an excited atom).

Relaxation
- The excited electron immediately returns, relaxation.
- During relaxation the energy difference is emitted as electromagnetic energy:
  - Big jump requires lots of energy.
  - Little jump requires small amounts of energy.

![Continuous Spectrum](image1.png)

![Emission Energy Line Spectra](image2.png)
Emission Spectra

- The pattern of emitted EM energy is called the emission or line spectrum for that element, and is characteristic for identifying an element.
- Our eyes see an average of these specific visible lines.
- Sodium – orange; potassium – purple; cesium – red; lithium – red; copper - green.

EM Spectrum

<table>
<thead>
<tr>
<th>High Energy</th>
<th>Low Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cosmic gamma X UV</td>
<td>IR microwaves TV radio</td>
</tr>
<tr>
<td>violet</td>
<td>blue, green, yellow, orange, red</td>
</tr>
</tbody>
</table>
Chem Quiz
Can cell phones cause cancer? (cell operate at microwaves)
A) Yes
B) No
C) No, if you use a head set
D) Can't tell

Electrons
- Valence electrons include the electrons on the outside of the atom
  - Increase as move from left to right on the periodic table
- Core electrons are the electrons on the inside of the atom
  - Number of core electrons the same for each row on periodic table

Chemical Stability
- Atoms like to have electron configurations similar to noble gases (He, Ne, Ar, Kr, Xe, Rn)
  - Bond with other atoms to reach this end
- Octet rule a generalization
  - For many elements, atoms will attempt to have 8 valence electrons
Lewis Dot Structures

- Group IA elements (alkali metals) have 1 valence electron: 1 dot
- Group IIA elements (alkaline earths) have 2 valence electrons: 2 dots
- Group VIII elements (noble gases) have eight dots, an Octet: 8 dots
  - He, has only 2 electrons, 2 dots,

<table>
<thead>
<tr>
<th>Periodic Table</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rows are periods</td>
</tr>
<tr>
<td>Columns are families</td>
</tr>
<tr>
<td>Since the elements have the same valence electrons, the chemistry is similar</td>
</tr>
</tbody>
</table>

Example

- Cu, Ag, Au
- All members of the same family
- There are similarities, but each element is not exactly the same
Types of Bonding

- Ionic — one atom gives electrons to the other
  - -- charges attract, -- & + repel
- Covalent — sharing of electrons
  - Polar covalent — unequal sharing
- Metallic — “sea” of electrons
- Molecules are stable groups of atoms
  - Similar to stable couples, the atoms can be in close proximity to each other

Metal/Nonmetal Reactions

- Reaction between metal and nonmetal produces ionic compounds
- Ionic compounds are usually crystalline solids
  - Caution to the WC rings
    - Very strong ionic bond

Ionic Bond

- Negative charges are attracted to positive charges
- Negative anions are attracted to positive cations
- The result is an ionic bond
- A three-dimensional crystal lattice of anions and cations is formed
**Metallic Bonds versus Ionic Bonds**

- Metals are ductile and can conduct electricity while ionic compounds are brittle and insulators. Why?
  - Metals have a "sea" of electrons, so electrical force is easily carried through it.
  - Ionic compounds have electrons fixed to atoms so no ability to conduct.
- The "sea" of electrons in metals makes it possible to move atoms more easily and keep the same bonding properties.
- If ionic compounds have their atoms move around, it is likely that a free of the same charge will repel each other, which causes ionic compounds to break into ionic charged metals.

**Covalent Bonds**

- Involve sharing of electrons.
  - 2 electrons shared, single bond
  - 4 electrons shared, double bond
  - 6 electrons shared, triple bond
- Stable groups of atoms are molecules.
- The atoms share electrons to get the same number of electrons as a noble gas.
  - A mutually-beneficial relationship.

**Multiple Bonds**

- Double and triple covalent bonds form.
  - $\text{H}_2\text{C} = \text{CH}_2$ ethene, $\text{C}_2\text{H}_4$
  - $\text{O} = \text{O}$ oxygen, $\text{O}_2$
  - $\text{H} = \text{C} = \text{H}$ ethyne, $\text{C}_2\text{H}_2$
  - $\text{N} = \text{N}$ nitrogen, $\text{N}_2$
Electronegativity
- Ability of an atom to attract electrons
- In covalent bonds, electronegative atoms act as "blanket hops"
- Further to the right and up on the periodic table, the more electronegative the atom is
  - Except the noble gases
  - F is the most electronegative

Polar Covalent Bonds
- When two dissimilar nonmetal atoms react the sharing of the pair of electrons can be unequal.
- The covalent bond is polar
- One atom is slightly positive, the other slightly negative
- Polar molecules attract each other by weak electrical attraction

Free Radicals
- Species with unpaired electrons
- High energy, unstable, highly reactive
- Capable of engaging in chain reactions
  - Halon fire extinguishers get rid of the chain reaction to put out fires
  - "electron scavengers" are added to jet fuel to make them harder to track on RADAR
Molecular Shapes

• Negative electrons repel each other
  – Electrons attracted to + nucleus, but are repelled by the other electrons
• Determines shapes of molecules
  – Two electron regions: linear
  – Three electron regions: triangular
  – Four electron regions: tetrahedral

Nomenclature

• Binary compounds: two elements
  – E.g., NaCl, FeI2, N2O4
• General format
  – First element: full name
  – Second element: root of name + “-ide”
  – E.g., NaCl: sodium chloride

Metal-Nonmetal Compounds

• Oxidation numbers are related to charges of ions
• Fixed oxidation number metal – nonmetal
  – Use general format
• Variable oxidation number metal – nonmetal
  – First name: name of element plus (oxidation number in Roman numerals)
  – E.g., FeCl3, iron(III) chloride
Metal-Nonmetal Compounds

- Use prefixes to denote the numbers of atoms of each element
- \( \text{SO}_3 \) - sulfur trioxide (mono is dropped for the first atom)
- \( \text{N}_2\text{O}_5 \) - dinitrogen tetroxide

Table 4.3 Prefixes That Indicate the Number of Atoms of an Element in a Covalent Compound

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Number of Atoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mono-</td>
<td>1</td>
</tr>
<tr>
<td>Di-</td>
<td>2</td>
</tr>
<tr>
<td>Tri-</td>
<td>3</td>
</tr>
<tr>
<td>Tetro-</td>
<td>4</td>
</tr>
<tr>
<td>Penta-</td>
<td>5</td>
</tr>
<tr>
<td>Hexa-</td>
<td>6</td>
</tr>
<tr>
<td>Hepta-</td>
<td>7</td>
</tr>
<tr>
<td>Octa-</td>
<td>8</td>
</tr>
<tr>
<td>Non-</td>
<td>9</td>
</tr>
<tr>
<td>Deca-</td>
<td>10</td>
</tr>
</tbody>
</table>

Polyatomic Ions

- A stable group of atoms, linked by covalent bonds, that bears an electrical charge
- \( \text{CO}_3^{2-} \) - carbonate ion
- \( \text{SO}_4^{2-} \) - sulfate ion
- \( \text{OH}^- \) - hydroxide ion
- \( \text{PO}_4^{3-} \) - phosphate ion
- \( \text{CN}^- \) - cyanide ion
- \( \text{NO}_2^- \) - nitrite ion
- \( \text{NH}_4^+ \) - ammonium ion

Common Ionic Compounds

- \( \text{NH}_4\text{NO}_3 \) - ammonium nitrate: fertilizer
- \( \text{CaCO}_3 \) - calcium carbonate: coral, limestone, marble
- \( \text{NH}_4\text{OH} \) - ammonium hydroxide: household cleaners, including glass cleaner
- \( (\text{NH}_4)_2\text{PO}_4 \) - ammonium phosphate: fertilizer (note since ammonium is +1 and phosphate is -3, there are 3 ammoniums)
Electrolytes

- Chemicals that release ions when they dissolve in water: sodium chloride, acids and bases.
- NaCl(s) → Na⁺(aq) + Cl⁻(aq)
- HCl(g) → H⁺(aq) + Cl⁻(aq)
- NaOH(s) → Na⁺(aq) + OH⁻(aq)
- Solutions conduct electricity