Chapter 3 – Atoms and Moles

Section 1 – Substances Are Made of Atoms
Atomic Theory

- Atomic Theory explains three separate scientific laws.
- Model on the right is more accurate depiction of an atom.
Law of Definite Proportions

- **The Law of Definite Proportions**

  - A chemical compound always contains the same elements in exactly the same proportions by weight or mass.

  - Every molecule of a compound is made of the same number and types of atoms.

- [Flash Video](#)
Law of Conservation of Mass

The Law of Conservation of Mass

- Mass cannot be created or destroyed in ordinary chemical and physical changes
- Mass of reactants = mass of products

Flash Video
Law of Multiple Proportions

The Law of Multiple Proportions

When two elements combine to form two or more compounds, the mass of one element that combines with a given mass of the other is in the ratio of small whole numbers.

<table>
<thead>
<tr>
<th>Name of compound</th>
<th>Description</th>
<th>As shown in figures</th>
<th>Formula</th>
<th>Mass O (g)</th>
<th>Mass N (g)</th>
<th>\frac{\text{Mass O (g)}}{\text{Mass N (g)}}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen monoxide</td>
<td>colorless gas that reacts readily with oxygen</td>
<td><img src="image" alt="Nitrogen monoxide" /></td>
<td>NO</td>
<td>16.00</td>
<td>14.01</td>
<td>\frac{16.00 \text{ g O}}{14.01 \text{ g N}} = 1.14 \frac{\text{g O}}{\text{g N}}</td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>poisonous brown gas in smog</td>
<td><img src="image" alt="Nitrogen dioxide" /></td>
<td>NO₂</td>
<td>32.00</td>
<td>14.01</td>
<td>\frac{32.00 \text{ g O}}{14.01 \text{ g N}} = 2.28 \frac{\text{g O}}{\text{g N}}</td>
</tr>
</tbody>
</table>

Flash Video
Dalton’s Atomic Theory (1808)

1.) All matter is composed of atoms, which cannot be subdivided, created, or destroyed

2.) Atoms of a given element are identical in their physical and chemical properties

3.) Atoms of different elements differ in the physical and chemical properties
Dalton’s Atomic Theory...continued

4.) Atoms of different elements combine in simple, whole-number ratios to form compounds

5.) In chemical reactions, atoms are combined, separated, or rearranged, but never created, destroyed, or changed
Chapter 3

Section 2 – Structure of Atoms
Subatomic Particles

- Atoms are composed of three subatomic particles
  - Protons, Neutrons, and Electrons
The PARTICLE ZOO
Subatomic Particle Plush Toys
FROM THE STANDARD MODEL OF PHYSICS & beyond!

QUARKS
- UP QUARK: A teeny little point inside the proton and neutron, it is friends forever with the down quark.
- CHARM QUARK: A second generation quark, he is charmed, indeed.
- TOP QUARK: This heavyweight champion doesn’t live long enough to make friends with anyone.
- DOWN QUARK: A tiny little point inside the proton and neutron, it is friends forever with the up quark.
- STRANGE QUARK: What’s so strange about this second generation quark?
- BOTTOM QUARK: This third generation quark is putting in the pounds.

FORCE CARRIERS
- PHOTON: The massless wavelike we know and love.
- GLUON: The “glue” of the strong nuclear force.
- W BOSON Z BOSON: As the carrier particles of the weak nuclear force, they’re downright obese.

LEPTONS
- ELECTRON-NEUTRINO: This minuscule bandit is so light, he is practically massless.
- ELECTRON: A familiar friend, this negatively charged, busy little guy likes to bond.
- MUON-NEUTRINO: Like the other Z neutrinos, he’s got an identity crisis from oscillation.
- MUON: A “heavy electron” who lives fast and dies young.
- TAU-NEUTRINO: He’s a tau now, but what type of neutrino will he be next?
- TAU: A “heavy muon” who can stand to lose a little weight.

THEORETICALS
- HIGGS SPECIAL!: To celebrate the start of the LHC, there will be a SPECIAL PRICE on HIGGS BOSONS on SEPTEMBER 10 only (PST).
- HIGGS BOSON: He’s the one everyone wants to meet, but for now he’s playing hard to get.
- GRAVITON: Still unobserved, yet theoretically everywhere, he’s got big legs for jumping branes.
- DARK MATTER: The mysterious missing mass. Difficult to see because he’s so dark.
- TACHYON: Can this devious and clever particle really travel faster than light?

NUCLEONS
- PROTON: We would not be here without her positivity.
- NEUTRON: He insists on remaining neutral.
Discovery of the Electron

- J.J. Thompson (1897)
  - Discovered electrons by using cathode rays
  - Vacuum tube, anode (+) at one end cathode (-) at other
Discovery of the Electron

- The “rays” were coming from the cathode metal
  - Reasoned the ray was negatively charged

- Confirmed by altering electric and magnetic fields

- The ray turned a “paddle wheel”

- Calculated the mass of an electron

Flash Video
Properties of an Electron

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>As shown in figures</th>
<th>Charge</th>
<th>Common charge notation</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron</td>
<td>$e, e^-, \text{ or } _{-1}^0 e$</td>
<td><img src="image" alt="Electron diagram" /></td>
<td>$-1.602 \times 10^{-19}$ C</td>
<td>-1</td>
<td>$9.109 \times 10^{-31}$ kg</td>
</tr>
</tbody>
</table>
Rutherford Discovered the Nucleus

- Mass and charge of electron did not account for the entire atom

- Thompson proposed the plum-pudding model
  - charges embedded in a ball of + charges
Rutherford Discovered the Nucleus

- Rutherford (1909) and the Gold Foil Experiment
  - Alpha particles (+) were directed at a thin sheet of gold foil
  - Measured the angle of deflection
Rutherford Discovered the Nucleus

- Particles should have went straight through
  - But small amounts were deflected
  - Only a very concentrated positive charge in a tiny space could deflect the alpha particles

- Flash Video

Rutherford reasoned that each atom in the gold foil contained a small, dense, positively charged nucleus surrounded by electrons. A small number of the alpha particles directed toward the foil were deflected by the tiny nucleus (red arrows). Most of the particles passed through undisturbed (black arrows).
Rutherford Discovered the Nucleus

Conclusions from Rutherford’s experiment

1.) Positive charges (protons) are found in a small area called the **nucleus**

2.) Mass must be larger than that of alpha particles

3.) Most of an atom is empty space (marble vs FB stadium)

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>As shown in figures</th>
<th>Charge</th>
<th>Common charge notation</th>
<th>Mass (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proton</td>
<td>$p, p^+, \text{ or } ^1_1p$</td>
<td><img src="image" alt="Proton" /></td>
<td>$+1.602 \times 10^{-19} \text{ C}$</td>
<td>+1</td>
<td>$1.673 \times 10^{-27} \text{ kg}$</td>
</tr>
<tr>
<td>Neutron</td>
<td>$n \text{ or } ^0_1n$</td>
<td><img src="image" alt="Neutron" /></td>
<td>$0 \text{ C}$</td>
<td>0</td>
<td>$1.675 \times 10^{-27} \text{ kg}$</td>
</tr>
</tbody>
</table>
Discovery of the Neutron

- The combined mass of electrons and protons did not account for atomic mass

- **Neutron** made up the missing mass

- No charge
  - Not deflected by electric or magnetic field
Coulombs' Law

- **Coulombs’ Law** states the closer two charges are, the greater the force between them.

- Neutrons help to stabilize the nucleus.
  - Otherwise protons would repel each other.

- All atoms with more than one proton also have neutrons.
**Atomic Number and Mass Number**

- **Atomic Number** is the number of protons an atom has.

- 113 identified elements, # 1-114 (Element 113 is yet to be discovered)
  - (Actually 118 now...)

- In an atom, the # of protons = the # of electrons
Atomic Number and Mass Number

- **Mass Number** is equal to the total # of particles in the nucleus (protons + neutrons)

- Neon
  - Mass # = 20
  - 20 particles – 10 protons = 10 neutrons
What is the mass number of this oxygen atom?
Atomic Number and Mass Number

- Mass number can vary among atoms of a single element

- Hydrogen (Atomic # = 1)
  - Mass number can be 1, 2, or 3

- Oxygen can have mass numbers of 16, 17, or 18

- Periodic Table shows **average atomic mass**
Isotopes

- **Isotopes** are atoms of the same element with varying #’s of neutrons

- Hydrogen-1, Hydrogen-2, Hydrogen-3
Atomic Symbols

- Atomic #: Lower Left
- Mass #: Upper Left
- Atomic Notation
  - S = 1 sulfur atom
  - 2S = 2 sulfur atoms
  - $S_2 = 2$ sulfur atoms chemically combined (molecule)
  - $S_8$

<table>
<thead>
<tr>
<th>Name of atom</th>
<th>Symbol</th>
<th>Number of neutrons</th>
<th>Mass number</th>
<th>Mass (kg)</th>
<th>Abundance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead-204</td>
<td>$^{204}_{82}$Pb</td>
<td>122</td>
<td>204</td>
<td>203.973</td>
<td>1.4</td>
</tr>
<tr>
<td>Lead-206</td>
<td>$^{206}_{82}$Pb</td>
<td>124</td>
<td>206</td>
<td>205.974</td>
<td>24.1</td>
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<tr>
<td>Lead-207</td>
<td>$^{207}_{82}$Pb</td>
<td>125</td>
<td>207</td>
<td>206.976</td>
<td>22.1</td>
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<tr>
<td>Lead-208</td>
<td>$^{208}_{82}$Pb</td>
<td>126</td>
<td>208</td>
<td>207.977</td>
<td>52.4</td>
</tr>
</tbody>
</table>
Chapter 3

Section 3 – Electron Configuration
Atomic Models

- **Rutherford**
  - Electrons revolve in circular or elliptical orbits around nucleus
  - Like planets

- **Bohr**
  - Electrons can only be certain distances from nucleus
  - Distance corresponds to energy of electron

- Difference in energy between two levels = **quantum** energy
Particle or Wave?

- Electrons act like both particles and waves
  - As waves, electrons have frequencies that correspond with their energy level

\[ E = h\nu \]

- Flash Video
Present Day Model

- Present Day Model
  - Electrons are located in **orbitals** (regions with high probability of finding electron – **electron cloud**)

- Spinning blades of fan analogy
  - Can see the general area where blade should be, but cannot tell exactly where any one blade is at a particular moment

- **Flash Video**
Electrons and Light

- Light is also a wave
  - $2.998 \times 10^8 \text{ m/s}$

- **Wavelength** = Distance between two peaks or troughs
  - Meters

- **Amplitude** = Height of wave

- **Period** = Time between two peaks or troughs

- **Frequency** = Cycles per second (determines energy)

- [Flash Video](#)
Electrons and Light

- **Electromagnetic Spectrum** – All frequencies or wavelengths of electromagnetic radiation

- Speed
  - Inverse relationship
Electromagnetic Spectrum

The electromagnetic spectrum is arranged from long to short wavelength or from low to high frequency.

- **Radio waves**
  - All radio and television stations broadcast radio waves.
  - Despite their name, microwaves are not the shortest EM waves.

- **Microwaves**
  - Infrared
    - Infrared means "below red."

- **Infrared**
  - Visible light
    - Visible light contains all the colors you can see.

- **Visible light**
  - Ultraviolet
    - Ultraviolet means "beyond violet."

- **Ultraviolet**
  - X rays
    - X rays were discovered in the early 1900s.

- **X rays**
  - Gamma rays
    - Gamma rays are produced by some nuclear reactions.
Electrons and Light

- **Photoelectric Effect**
  - 1905 – Einstein – Light strikes a metal and electrons are released
  - Proved light can also be a particle
  - Energy of light determined by its frequency
Electrons and Light

- High-voltage current passed through tube filled with hydrogen
  - Lavender color light
  - Use prism to break light into individual colors (wavelengths)

- Every element gives a unique pattern of colors!
  - These patterns are called **line-emission spectrum**
Excited hydrogen atoms emit a pinkish glow. When the visible portion of the emitted light is passed through a prism, it is separated into specific wavelengths that are part of hydrogen’s line-emission spectrum.
Electrons can move from low energy level (orbital) to high by absorbing energy.

- Electron emits a photon of light when it goes back to lower energy level.

Excited hydrogen atoms emit a pinkish glow. When the visible portion of the emitted light is passed through a prism, it is separated into specific wavelengths that are part of hydrogen's line-emission spectrum.
Electrons and Light

- Electron at its lowest energy level is called **ground state**

- If electron gains energy it moves into an **excited state**
  - It will “fall back” to its ground state (releasing photon)

- Electron in hydrogen can move only from certain energy levels →

- **Flash Video**
Quantum Numbers

- **Quantum Model** – Present model of an atom

- Scientists have assigned 4 quantum numbers to describe where electrons can be found
Quantum Numbers

1.) **Principal Quantum Number**
- Symbolized by letter – \( n \)
- Indicates what main energy level electron is in
- As \( n \) increases, distance from nucleus increases
Quantum Numbers

2.) Angular Momentum Quantum Number

- Sublevel of main energy level
- Symbolized by letter – \( l \) (lowercase L)
- Indicates shape of orbital

- \( l = 0 \) corresponds to an s orbital
- \( l = 1 \) to a p orbital
- \( l = 2 \) to a d orbital
- \( l = 3 \) to an f orbital
Quantum Numbers

- **Angular Momentum Quantum Numbers (shapes of orbitals)**

  - **a** The $s$ orbital is spherically shaped. There is one $s$ orbital for each value $n = 1, 2, 3...$ of the principal number.

  - **b** For each of the values $n = 2, 3, 4...$, there are three $p$ orbitals. All are dumbbell shaped, but they differ in orientation.

  - **c** For each of the values $n = 3, 4, 5...$, there are five $d$ orbitals. Four of the five have similar shapes, but differ in orientation.
s Orbital

$p_x$ Orbital

$p_y$ Orbital

$p_z$ Orbital

All $p$ orbitals full
Quantum Numbers

3.) **Magnetic Quantum Number**
- Symbolized by letter – *m*
- Indicates orientations of orbitals around nucleus

- 1 type of *s* orbital
- 3 types of *p* orbitals
- 5 types of *d* orbitals
- 7 types of *f* orbitals

<table>
<thead>
<tr>
<th><em>n</em></th>
<th><em>l</em></th>
<th><em>m</em></th>
<th>Orbital name</th>
<th>Number of orbitals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1s</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0</td>
<td>2s</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>(-1, 0, 1)</td>
<td>2p</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0</td>
<td>3s</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>(-1, 0, 1)</td>
<td>3p</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>(-2, -1, 0, 1, 2)</td>
<td>3d</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>0</td>
<td>0</td>
<td>4s</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>(-1, 0, 1)</td>
<td>4p</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>(-2, -1, 0, 1, 2)</td>
<td>4d</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>3</td>
<td>(-3, -2, -1, 0, 1, 2, 3)</td>
<td>4f</td>
<td>7</td>
</tr>
</tbody>
</table>
The s orbital is spherically shaped. There is one s orbital for each value of the principal number.

For each of the values of n = 3, 4, 5..., there are five d orbitals. Four of the five have similar shapes, but differ in orientation.
Quantum Numbers

4.) Spin Quantum Number

- Symbolized by +1/2 or -1/2 (↑ or ↓)
- Indicates orientation of magnetic field around electron
- A single orbital can hold only two electrons, each must have opposite spins

\[ E = h\nu \]
Quantum Numbers

- [Flash Video](#) Review of Quantum Numbers
**Electron Configurations**

- **Pauli Exclusion Principle** – Maximum of two electrons per orbital
  - (+1/2 or -1/2 )

- **Electron Configurations** show the arrangement of electrons in an atom

- Hydrogen – 1s
- Oxygen – 1s\(^2\)2s\(^2\)2p\(^4\)
Electron Configurations

- **Aufbau Principle** – Electrons fill orbitals with lowest energy first
  - Use chart to determine fill order

<table>
<thead>
<tr>
<th>Principle</th>
<th>Quantum Number</th>
<th>Energy Level, &quot;n&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1s</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>2s 2p</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>3s 3p 3d</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>4s 4p 4d 4f</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>5s 5p 5d 5f</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>6s 6p 6d 6f</td>
<td>6</td>
</tr>
<tr>
<td>7</td>
<td>7s 7p 7d 7f</td>
<td>7</td>
</tr>
</tbody>
</table>

Order: 1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p

- [Flash Video]
Periodic Table Trends

s-block

d-block

p-block

Lanthanides

Actinides

Ce

Th
**Electron Configurations**

- **Hund’s Rule** – Orbitals of the same n and l quantum numbers are each occupied by one electron before any pairing occurs.

- **Orbital Diagram**
Electron Configurations are often abbreviated using the configurations of the noble gases

- [Ne]$3s^23p^4$
  - Instead of $1s^22s^22p^63s^23p^4$

- [Ar]$4s^2$

- Flash Video
Electron Configuration Fill Order

Order: 1s 2s 2p 3s 3p 4s 3d 4p 5s 4d 5p 6s 4f 5d 6p 7s 5f 6d 7p
Chapter 3

Section 4 – Counting Atoms
Atomic Mass

- Special mass unit for measuring mass of an atom
  - **Atomic Mass Unit (AMU)**
  - Also referred to as a Dalton (Da)

- AMU is defined as – 1/12 the mass of Carbon-12
  - Proton = ~1 amu
  - Neutron = ~1 amu
  - Electron = not counted
Mole

- **Mole** – Number of atoms in exactly 12 grams of carbon-12
  - SI unit for amount of a substance

- **Molar Mass** – The mass in grams of one mole of an element
  - Simply replace AMU with grams per mole

- Oxygen = 15.9994 AMU, therefore 15.9994 grams/mole
Avogadro's Number

- Scientists have determined the number of particles present in one mole of a substance, this is called **Avogadro’s Number**
- $6.022 \times 10^{23}$ particles (atoms or molecules) per mole
Practice Questions!

Page 102 #1-4

- What is the mass in grams of 1.00 mol of uranium?
- What is the mass in grams of 0.0050 mol of uranium?
- Calculate the number of moles of 0.850 g of hydrogen atoms. What is the mass in grams of 0.850 mol of hydrogen atoms?
- Calculate the mass in grams of 2.3456 mol of lead. Calculate the number of moles of 2.3456 g of lead.

Page 103 #1-3

- How many atoms are in 0.70 mol of iron?
- How many moles of silver atoms are represented by $2.888 \times 10^{23}$ atoms?
- How many moles of osmium are represented by $3.5 \times 10^{23}$ atoms?