AP Chemistry

Unit #2

Chapter 2 – Zumdahl

Atom, Molecules, & Ions

Students should be able to:

✓ Distinguish between protons, neutrons, and electrons and be able to describe the composition of an atom of any particular element in terms of these subatomic particles.
✓ Describe the basic anatomy of an atom and the ratio of the number of the nucleus to that of the atom.
✓ Know the difference between an atom, an ion, and a molecule.
✓ Have a basic knowledge of the periodic table, which includes being able to predict whether an element is a metal or a nonmetal, and what will be the probable charge of its ion.
✓ Distinguish between empirical, molecular, and structural formulas.
✓ Be able to write the correct name of an inorganic compound from its formula and vice versa.

Keywords:

- Atom
- nucleus
- electron
- atomic number
- metal
- molecular formula
- ionic compound
- ion
- molecule
- proton
- atomic mass unit
- mass number
- nonmetal
- empirical formula
- polyatomic ion
- periodic group
- molecule
- proton
- atomic mass unit
- mass number
- nonmetal
- empirical formula
- polyatomic ion
- periodic group
- ion
- neutron
- isotope
- nucleus
- metalloid
- molecular compound
- cation
I. The Atomic Theory of Matter

A. What Is Dalton's Atomic Theory of Matter?

Dalton's Postulates:
1. Elements are made up of atoms.
2. All atoms of an element are identical; atoms of diff. elem.'s are fund. diff.
3. Atoms of different elements combine to form compounds (that have same elements/ratios)
4. Chem rxns involve the reorganization of atoms; those atoms are not changed.

B. What Is Dalton's "Law of Multiple Proportions"?

\[
\begin{align*}
\text{Comp. A} & : 1.750 \text{g} \\
\text{Comp. B} & : 0.875 \text{g} \\
\text{Comp. C} & : 0.4375 \text{g}
\end{align*}
\]

Mass of N that combines w/ 18 O

\[
\begin{align*}
\text{N:O} & \quad 0 & \quad 18 \\
1.750 & \quad 1 & \quad 9.75 \times 10^{-2} \\
0.875 & \quad 1 & \quad 4.375 \times 10^{-2} \\
0.4375 & \quad 1 & \quad 2.25 \times 10^{-2}
\end{align*}
\]

II. The Discovery of Atomic Structure

A. What Is a Cathode Ray Tube?

JJ Thomson
disc. e^- & that they're neg.
→ What was discovered by using a cathode ray tube?

B. What contribution did JJ Thomson make to the modern model of the atomic structure?

Plum pudding

C. What and how did Robert Millikan discover in his famous "Oil-drop experiment"?

- Rel. charge on e^- (in coulombs)
- Charge : mass ratio of an e^-
D. What is radioactivity? Nuclear instability

1. What is an alpha particle (α)? $^4\text{He} \rightarrow ^4\alpha + 2^0\text{He}$
   (equiv. to He nucleus)

2. What is a beta particle ($\beta^-$)? $\beta^- = -e \quad \beta^+ = +e$

E. What was Rutherford’s “Gold-Foil Experiment”?

- Atom is mostly empty space
- Dense, Positive core = nucleus

1. What conclusions did Rutherford draw from the results of his experiment?
   Nuclear Theory

F. Compare and contrast the different models of the atom as proposed by:

<table>
<thead>
<tr>
<th></th>
<th>Dalton</th>
<th>Thomson</th>
<th>Rutherford</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Similarities</strong></td>
<td></td>
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</tr>
<tr>
<td><strong>Differences</strong></td>
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</tbody>
</table>
III. The Modern View of Atomic Structure

A. The Basic Structure of the Atom:
- **Nucleons** – protons and neutrons found in the nucleus.
- **Electrons** – found in “energy clouds” around the nucleus.

B. Size and Mass of the Atom:
1. **The Atomic Mass Unit** – a derived unit based on Carbon – 12. 1 amu is approximately the mass of 1 proton (1.0073).
   \[1 \text{ amu} = 1.66054 \times 10^{-24} \text{g}\]
2. **The Angstrom (Å)** – a convenient (non-SI) unit of length that is used to measure diameters of atoms (1 angstrom = 10^{-10} m).

C. **Atomic Numbers** – (Z) the number of protons in the nucleus.

D. **Mass Numbers** – the total number of protons plus neutrons in an atom.

E. **Isotopes** – Atoms of a given element that differ in the number of neutrons (and therefore mass).

   **The average atomic mass** – is based on the mass and abundance of all the naturally occurring isotopes of the element.
   \[
   \text{Average atomic mass} = \frac{\sum (\text{mass of each isotope}) \times (\text{abundance of each isotope})}{100}
   \]

IV. The Periodic Table

A. **Families & Groups of Elements**:
1. Group 1 = Alkali Metals
2. Group 2 = Alkaline Earth Metals
3. Group 17 = Halogens
4. Group 18 = Noble Gases
5. Groups 3 – 12 = Transition Metals

\}{4 \text{ FAMILIES}}
### B. Periods: Represent different "energy levels" or "shells" of electrons in the atom.

**THE PERIODIC TABLE**

<table>
<thead>
<tr>
<th>Group</th>
<th>(\text{IA})</th>
<th>(\text{IIA})</th>
<th>(\text{IIIA})</th>
<th>(\text{IVA})</th>
<th>(\text{VA})</th>
<th>(\text{VIA})</th>
<th>(\text{VIIA})</th>
<th>(\text{IIB})</th>
<th>(\text{IIB})</th>
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<th>(\text{IIB})</th>
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<td>2</td>
<td>Li</td>
<td>Be</td>
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<td>Mg</td>
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<td>In</td>
<td>Tl</td>
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<td>In</td>
<td>Tl</td>
<td>Pb</td>
<td>Bi</td>
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<td>Ca</td>
<td>Sc</td>
<td>Ti</td>
<td>V</td>
<td>Cr</td>
<td>Mn</td>
<td>Fe</td>
<td>Co</td>
<td>Ni</td>
<td>Cu</td>
<td>Zn</td>
<td>Ga</td>
<td>Ge</td>
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<td>La</td>
<td>Ce</td>
<td>Pr</td>
<td>Nd</td>
<td>Pm</td>
<td>Sm</td>
<td>Eu</td>
<td>Gd</td>
<td>Tb</td>
<td>Dy</td>
<td>Ho</td>
<td>Er</td>
</tr>
<tr>
<td>5</td>
<td>Ba</td>
<td>La*</td>
<td>Cb</td>
<td>Np</td>
<td>Am</td>
<td>Cm</td>
<td>Bk</td>
<td>Cf</td>
<td>Es</td>
<td>Ac*</td>
<td>Pa*</td>
<td>210</td>
<td>Rf</td>
<td>114</td>
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<tr>
<td>6</td>
<td>Ra</td>
<td>Ac</td>
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</table>

#### Key:
- **Metal**: Metals are typically good conductors of electricity and heat, they often have a shiny appearance, and they are malleable and ductile.
- **Semi-metal**: These elements are not as good conductors of electricity as metals but better than nonmetals. They are brittle, non-lustrous, and poor conductors of electricity and heat.
- **Nonmetal**: Nonmetals are typically poor conductors of electricity and heat, they are non-lustrous, and they are brittle.

### A. Metal vs. Nonmetal Elements

**Metal Characteristics**
- Malleable (easily pounded into flat sheets)
- Ductile (can be drawn out to form wire)
- Lustrous (shiny)
- Good conductors (electric/heat)
- Sea of valence e-
- Form + ions (cations)

**Nonmetal Characteristics**
- Brittle (not malleable or ductile)
- Dull (not shiny)
- Poor conductors (electric/heat)
- Tend to share electrons and form covalent bonds
- Form - ions (anions)
V. **Molecules and Ions**

A. **Molecules** - A chemical combination of two or more nonmetal atoms.

1. **Diatomic Molecules** - Some elements exist as a molecule in the pure state (7-up).  
   \[ \text{H}_2, \text{O}_2, \text{F}_2, \text{Br}_2, \text{I}_2, \text{N}_2, \text{Cl}_2 \]

B. **Chemical Formulas** -

1. **Molecular Formulas** - Uses element symbols to convey the actual number of atoms in a compound.  
   \[ C_6\text{H}_{12}\text{O}_6 = \text{Glucose} \]

2. **Empirical Formulas** - A formula that shows the simplest ratio of elements in a compound.  
   \[ C\text{H}_2\text{O} = \text{Glucose} \]

3. **Structural Formulas** - A formula that indicates the actual number of atoms and the bonds that they form in a substance.  
   \[ \text{H}_2\text{C} \text{H}-\text{C}=-\text{H}_2 \]

C. **Ions** - "charged atoms" - particles that have gained or lost electrons.

1. **Anions** - negatively charged particles (caused by a gain of electrons.)
2. **Cations** - positively charged particles (caused by a loss of electrons.)

3. **Polyatomic Ions** -

<table>
<thead>
<tr>
<th>Name</th>
<th>Charge</th>
<th>Formula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonium (NH₄⁺)</td>
<td>1⁺</td>
<td>NH₄⁺</td>
</tr>
<tr>
<td>Carbonate (CO₃⁻₂)</td>
<td>2⁻</td>
<td>CO₃⁻₂</td>
</tr>
<tr>
<td>Chromate (Cr₂O₇⁻³)</td>
<td>2⁻</td>
<td>Cr₂O₇⁻³</td>
</tr>
<tr>
<td>Dichromate (CrO₄⁻²)</td>
<td>2⁻</td>
<td>CrO₄⁻²</td>
</tr>
<tr>
<td>Ethanesulfate / Oxalate</td>
<td>2⁻</td>
<td>C₂O₄⁻²</td>
</tr>
<tr>
<td>Hydrogen carbonate</td>
<td>1⁻</td>
<td>HCO₃⁻</td>
</tr>
<tr>
<td>Hydroxide (OH⁻)</td>
<td>1⁻</td>
<td>OH⁻</td>
</tr>
<tr>
<td>Manganese (II) (Ferric)</td>
<td>1⁻</td>
<td>MnO₄⁻</td>
</tr>
<tr>
<td>Nitrate (NO₃⁻)</td>
<td>1⁻</td>
<td>NO₃⁻</td>
</tr>
<tr>
<td>Nitrite (NO₂⁻)</td>
<td>1⁻</td>
<td>NO₂⁻</td>
</tr>
<tr>
<td>Phosphate (PO₄⁻³)</td>
<td>3⁻</td>
<td>PO₄⁻³</td>
</tr>
<tr>
<td>Sulfite (SO₃⁻²)</td>
<td>2⁻</td>
<td>SO₃⁻²</td>
</tr>
<tr>
<td>Sulfite (SO₄⁻²)</td>
<td>2⁻</td>
<td>SO₄⁻²</td>
</tr>
</tbody>
</table>
D. Predicting Ionic Charge — The location of an element on the periodic table will allow for a prediction of ionic charge.

Ex) Group 1 = +1
Group 17 = -1  (Octet Rule)

E. Ionic Compounds — A compound created by a transfer of electron(s) from a metal atom to a nonmetal atom.

Ex) NaCl — sodium chloride

Mg$^{2+}$ N$^{-3}$  (Cross-cross method for writing ionic compounds)

VI. Naming Inorganic Compounds

A. Naming Ionic Compounds — names of ionic compounds are derived from the ions that it is composed of.

1. Cations — The "+" ion’s name comes straight from the elements name. When multiple "+" ions exist for an element, we use Roman Numerals to denote the ions charge.

2. Anions — The "-" ion’s name ends in "-ide"

Examples: Zinc Chloride = ________________

$Fe_2O_3$ = ________________

$NH_4NO_3$ = ________________

Copper (II) Sulfate = ________________

B. Naming Acids

1. Binary Acids (contain 2 elements) — start with "hydro-" followed by the name of the anion, replacing the suffix "-ine" with "-ic."

Examples: HCl = hydrochloric acid
Hydrobromic Acid =
H$_2$S = hydrosulfuric acid
2. **Ternary Acids (or Oxyacids)**—replace the suffix in the name of the polyatomic ion according to the following rule:

- **"ate"** → **"ic"**
- **"ite"** → **"ous"**

Then add the word "acid."

<table>
<thead>
<tr>
<th>Formula and name of oxyanion</th>
<th>Formula and name of oxyacid</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClO(^-)</td>
<td>Hypochlorite</td>
</tr>
<tr>
<td>ClO(_2)(^-)</td>
<td>Chlorite</td>
</tr>
<tr>
<td>ClO(_3)(^-)</td>
<td>Chlorate</td>
</tr>
<tr>
<td>ClO(_4)(^-)</td>
<td>Perchlorate</td>
</tr>
</tbody>
</table>

Examples:
- \(\text{H}_2\text{SO}_4 = \text{sulfuric acid}\)
- \(\text{Nitric Acid} = \text{NO}_3 = \text{Nitrate}\)
- \(\text{H}_2\text{SO}_3 = \text{sulfurous acid}\)

C. **Naming Molecular Compounds**

1. Using Prefixes—

<table>
<thead>
<tr>
<th># of atoms of element</th>
<th>Prefix</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
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<tr>
<td>2</td>
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</table>

2. Examples

<table>
<thead>
<tr>
<th>Formula</th>
<th>Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>H(_2)O</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>C(_2)(_2)</td>
<td>Sulfur hexafluoride</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>Nitrogen dioxide</td>
</tr>
</tbody>
</table>