Chemical Symbols

- Each element is abbreviated using a one- or two-lettered chemical symbol.
- Usually, the symbol is derived from the name of the element (there are some exceptions!)
  - C is the symbol for carbon
  - Cd is the symbol for cadmium
- When a symbol has two letters, the first is capitalized and the second is lower case.
Other Chemical Symbols

• For some elements, the chemical symbol is derived from the original Latin name.

• For example:

<table>
<thead>
<tr>
<th>Element</th>
<th>Symbol</th>
<th>Latin Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>Au</td>
<td>Aurum</td>
</tr>
<tr>
<td>Silver</td>
<td>Ag</td>
<td>Argentum</td>
</tr>
<tr>
<td>Copper</td>
<td>Cu</td>
<td>Cuprum</td>
</tr>
<tr>
<td>Sodium</td>
<td>Na</td>
<td>Natrium</td>
</tr>
<tr>
<td>Iron</td>
<td>Fe</td>
<td>Ferrum</td>
</tr>
</tbody>
</table>

Chapter 4 3

Chemical Formulas

• A particle composed of two or more nonmetal atoms is a **molecule**.

• A **chemical formula** expresses the number and types of atoms in a molecule.

• The chemical formula of sulfuric acid:

\[ H_2SO_4 \]
Writing Chemical Formulas

**Rule 1:** The number of each type of atom in a molecule is indicated with a *subscript* in a chemical formula.

**Rule 2:** If there is only one atom of a certain type, *no ‘1’ is used.*

*For Example:* A molecule of the vitamin Niacin has 6 carbon atoms, 6 hydrogen atoms, 2 nitrogen atoms, and 1 oxygen atom. What is the chemical formula?

\[
\text{C}_6\text{H}_6\text{N}_2\text{O}
\]

Interpreting Chemical Formulas

- Some chemical formulas use parenthesis to clarify atomic composition.
- Trinitrotoluene (TNT) has chemical formula:

\[
\text{C}_7\text{H}_5(\text{NO}_2)_{3}
\]

Dalton Model of the Atom

- John Dalton proposed that all matter is made up of tiny particles.
- These particles are molecules or atoms.
  - Molecules (or Compounds) can be broken down into atoms by chemical processes.
  - Atoms cannot be broken down by chemical or physical processes.

**Dalton’s Atomic Theory**
1. Each element is composed of tiny, individual particles called atoms.
2. Atoms are indivisible; they cannot be created or destroyed.
3. All atoms of an element are identical and have the same properties.
4. Atoms of different elements have different properties.
5. Atoms of one element may combine with atoms of other elements (usually in whole number ratios) to form molecules
   - Each molecule always contains the same type and number of atoms.

Chapter 4  Atoms can combine in more than one ratio to form different molecules.

Dalton’s Theory: Subatomic Particles

- About 50 years after Dalton’s theory was established, evidence was seen that atoms were divisible.
- This challenged the 2nd postulate of Dalton’s theory.
- Two subatomic particles were discovered:
  - Negatively charged electrons, \(e^-\)
    - Very low mass
  - Positively charged protons, \(p^+\)
    - About 1800 times as heavy as the electron
**Thomson’s Subatomic Model of the Atom**

- **J.J. Thomson** proposed a subatomic model of the atom in 1903 based on the discoveries of the electron and the proton.

- Thomson proposed that the electrons were distributed evenly throughout a homogeneous sphere of positive charge.

- This was called the “Plum Pudding” model of the atom.

**Rutherford’s Gold Foil Experiment**

- In 1911, **Ernest Rutherford** tested Thompson’s proposed model by firing positively charged alpha particles (Helium atoms without their electrons) at thin gold foils.

- If the “plum pudding” model of the atom was correct, most $\alpha$-particles should pass straight through the foil.
Explanation of Scattering

- Most of the alpha particles passed through the foil because an atom is largely empty space.
- At the center of an atom is the **atomic nucleus** which contains the atom’s protons.
- The α-particles that bounced backwards did so after striking the dense nucleus.
- The ones that bend do so because of repulsion by the nucleus.

Rutherford’s Nuclear Model of the Atom

- Based on his results, Rutherford proposed a new model of the atom:
  1. Every atom contains an extremely small, extremely dense nucleus.
  2. All of the positive charge and nearly all of the mass of an atom is concentrated in this nucleus.
  3. The nucleus is surrounded by a much larger volume of nearly empty space that makes up the rest of the atom.
  4. The space outside the nucleus is very sparsely populated by the electrons, the total charge of which balances the positive charge of the protons.
- An atom has a diameter of about $1 \times 10^{-10}$ cm and the nucleus has a diameter of about $1 \times 10^{-15}$ cm.
- To put it in perspective, if an atom were the size of the Meadowlands Stadium, the nucleus would be like a marble on the 50 yard line.
Another Subatomic Particle

- Based on the heaviness of the nucleus, Rutherford predicted that it must contain neutral particles in addition to protons.

- As predicted by Rutherford, a third subatomic particle, the Neutron ($n^0$), was discovered about 30 years later.
  - A neutron is about the size of a proton without any charge.

### Nuclear Symbol (aka. Atomic Notation)

- Each element has a characteristic number of protons in the nucleus. This is the **atomic number**, $Z$.

  \[
  \text{Atomic number (Z)} = \# \text{ of } p^+ 
  \]

- The total number of protons and neutrons in the nucleus of an atom is the **mass number**, $A$.

  \[
  \text{Mass number (A)} = (\# \text{ of } p^+) + (\# \text{ of } n^0)
  \]

- We use **atomic notation** to display the number of protons and neutrons in the nucleus of an atom:

  \[
  A \overset{Z}{\underset{Y}{Sy}} \quad \text{Charge (Y)} = (\# \text{ of } p^+) - (\# \text{ of } e^-)
  \]

  \[
  \text{mass number (p$^+$ and n$^0$)} \quad \text{atomic number (p$^+$)}
  \]

  \[
  \text{symbol of the element}
  \]

---

*An atomic mass unit (amu) is a very small unit of mass, $1.66 \times 10^{-24}$ g, used for atomic-scale particles.*

© 2004 Thomson/Scotsman
Using Atomic Notation

- The element is sodium (symbol Na).
- What is the Atomic Number?
- How many protons does sodium have?
- What is the mass number?
- How many neutrons does Sodium have?

\[ A - Z = 23 - 11 = 12 \text{ neutrons} \]

Fill in the Following Table

<table>
<thead>
<tr>
<th>Atomic Element</th>
<th>Atomic Number</th>
<th>Mass Number</th>
<th>Number of Protons</th>
<th>Number of Electrons</th>
<th>Number of Neutrons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cl</td>
<td>17</td>
<td>1</td>
<td>1</td>
<td>19</td>
<td>12</td>
</tr>
<tr>
<td>Ba</td>
<td>78</td>
<td>137</td>
<td>78</td>
<td>61</td>
<td>117</td>
</tr>
<tr>
<td></td>
<td>78</td>
<td>59</td>
<td>78</td>
<td>78</td>
<td>117</td>
</tr>
</tbody>
</table>
Isotopes

• Atoms of the same element **always** have the same number of protons (the same atomic number).

• However, atoms of the same element can (and do!) have different masses!

  **What could cause this?**

• Atoms of the same element that have a different number of neutrons in the nucleus are called **isotopes**.

• Isotopes have the **same atomic number** but **different mass numbers**.
  – The amount of each isotope present in nature is called its **abundance**.

Isotope Notation

• We often refer to an isotope by stating the name of the element followed by the **mass number**.
  – Cobalt-60 is \(^{60}\text{Co}\)
  – Carbon-14 is \(^{14}\text{C}\)

• How many protons and neutrons does an atom of mercury-202 have?
  – The atomic number of Hg is 80, so it has **80 protons**
  – Hg-202 has a mass number of 202:
    \[
    202 - 80 = 122 \text{ neutrons}
    \]
Atomic Mass

- The **atomic mass** of an element is the average mass of all atoms of an element as they occur in nature.

- Since not all isotopes of an atom are present in equal proportions (different **abundances**!), we must calculate a weighted average.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Mass (amu)</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>1.007825035</td>
<td>99.985</td>
</tr>
<tr>
<td>D</td>
<td>2.014101779</td>
<td>0.015</td>
</tr>
<tr>
<td>He</td>
<td>3.016092010</td>
<td>0.000137</td>
</tr>
<tr>
<td>Ne</td>
<td>4.00260199</td>
<td>99.999863</td>
</tr>
<tr>
<td>C</td>
<td>12 (exactly)</td>
<td>98.93</td>
</tr>
<tr>
<td>O</td>
<td>15.99943156</td>
<td>99.832</td>
</tr>
<tr>
<td>Ne</td>
<td>15.00010760</td>
<td>0.568</td>
</tr>
<tr>
<td>F</td>
<td>18.9984032</td>
<td>100</td>
</tr>
<tr>
<td>Cl</td>
<td>35.4517865</td>
<td>24.22%</td>
</tr>
</tbody>
</table>

Calculating Atomic Mass

- Chlorine has two isotopes:
  - $^{35}$Cl with a mass of 34.969 amu and 75.78% abundance
  - $^{37}$Cl with a mass of 36.966 amu and 24.22% abundance

The average atomic mass of chlorine is:

\[
(34.969 \text{ amu})(0.7578) + (36.966 \text{ amu})(0.2422) = 35.45 \text{ amu}
\]
Periodic Notation

- The notation on the periodic table is slightly different than the atomic notation.
- The periodic table shows the **atomic number**, **symbol**, and **atomic mass** for each element.

What is the difference between the Periodic Notation and the Atomic Notation?

- The Periodic Table lists the atomic mass not the mass number!

Mendeleev’s Periodic Table

- In the 1869, **Dmitri Mendeleev** proposed that the properties of the chemical elements repeat at regular intervals when arranged in order of increasing **atomic mass**.
- Mendeleev is the architect of the modern periodic table.

- He arranged his periodic table in columns by the formula of the element’s oxide.
Prediction of New Elements

• Mendeleev noticed that there appeared to be some elements missing from the periodic table.

• He was able to accurately predict the properties of the unknown element *ekasilicon* in 1869.

• The element was actually discovered in 1886 (Germanium).

<table>
<thead>
<tr>
<th>Property</th>
<th>Ekasilicon Predicted (1869)</th>
<th>Germanium Discovered (1886)</th>
</tr>
</thead>
<tbody>
<tr>
<td>color</td>
<td>gray</td>
<td>gray</td>
</tr>
<tr>
<td>atomic mass</td>
<td>72 amu</td>
<td>72.6 amu</td>
</tr>
<tr>
<td>density</td>
<td>5.5 g/mL</td>
<td>5.32 g/mL</td>
</tr>
<tr>
<td>melting point</td>
<td>very high</td>
<td>932°C</td>
</tr>
<tr>
<td>formula of oxide</td>
<td>EkO₂</td>
<td>GeO₂</td>
</tr>
<tr>
<td>density of oxide</td>
<td>4.7 g/mL</td>
<td>4.70 g/mL</td>
</tr>
<tr>
<td>formula of chloride</td>
<td>EkCl₄</td>
<td>GeCl₄</td>
</tr>
<tr>
<td>boiling point of chloride</td>
<td>108°C</td>
<td>86°C</td>
</tr>
</tbody>
</table>

The Modern Periodic Table

• *H.G.J. Moseley* discovered that the nuclear charge increased by 1 for each element in the Mendeleev’s table.

• He concluded that the changing atomic number rather than the changing mass explained the repeating trends of the elements.

• The periodic law states that the properties of elements recur in a repeating pattern when arranged according to increasing atomic number.

• With the introduction of the concept of electron energy levels by *Niels Bohr*, the periodic table took its current arrangement.

Chemical Families

• Elements within a group (a column) have similar chemical properties
• Several of these groups form chemical families
• Trends among these families are most obvious for the main group elements.

Group 1A: Alkali Metals

• With the exception of hydrogen, all the elements in group 1A are known as the **Alkali metals**
• These elements all have one valence electron, and like to form +1 ions
• As you move down the group, the reactivity of the metal increases
• Alkali metals do not look like what we think of as a metal (shiny) because they react readily with oxygen which coats their outer layer.
• These elements are good conductors of electricity and can be readily formed into foils and wires.
Group 2A: Alkali Metals

- The elements in group 2A are known as the **Alkaline Earth metals**
- These elements all have two valence electrons, and like to form +2 ions
- As you move down the group, the reactivity of the metal increases
- These elements are good conductors of electricity and can be readily formed into foils and wires.

Group 7A: The Halogens

- The elements in group 7A are known as the **Halogens**
- These elements are **non-metals**
- The Halogens have seven valence electrons, and like to form -1 ions
- As you move down the group, the reactivity of the non-metal decreases
- These elements exist as solids, liquids or gases in their native state.
- The density, melting point and boiling point all increase as you move down the group.
The elements in group 8A are known as the **Nobel Gases**

These elements are **non-metals** and have eight valence electrons.

Because they have eight valence electrons, these elements do not like to form ions at all.

The Nobel Gases do not generally react with other elements and only a few compounds containing these elements are known.

These elements exist as gases in their native state.

The density, melting point and boiling point all increase as you move down the group.