Chapter 4
Atoms and Elements

Opening figure showing a shore scene with molecules of O₂, N₂, triethyl amine (CH₃CH₂)₃N, and rocks made of silicates containing silicon and oxygen.
Chapter 4 Atoms and Elements

4.1 Experiencing atoms at Tiburon
4.2 Indivisible: The Atomic Theory
4.3 The Nuclear Atom
4.4 The Properties of Protons, Neutrons and Electrons
4.5 Elements: Defined by the Number of Protons
4.6 Looking for Patterns: The Periodic Law and the Periodic Table
4.7 Ions: Losing or Gaining Electrons
4.8 Isotopes: When the Number of Neutrons Varies
4.9 Atomic Mass
4.1 Experiencing Atoms at Tiburon (San Francisco Bay)
Atoms are everywhere

- Oxygen
- Water
- Nitrogen
- Triethylamine $(\text{CH}_3\text{CH}_2)_3\text{N}$
- Silicate rocks contain silicon and oxygen
Experiencing Atoms

- Atoms are tiny pieces of elements.
- If an atom in a pebble was enlarged to the size of the pebble, the pebble would be as large as Mt Everest.

Figure 4.1 illustrating the analogy above
Atom in pebble $\rightarrow$ to size of pebble = pebble the size of Mt. Everest.
Experiencing Atoms

• 91 naturally occurring elements.
  ✓ Over 20 have been made in laboratories
• Each element has its own type of atom.
• Properties of atoms $\rightarrow$ properties of matter
• Elements are listed in the Periodic Table
4.2 Indivisible: The Atomic Theory
Two Views of the Divisibility of Matter

• Infinite division. A piece of paper can be cut in half over and over with no end
• A smallest particle exist that can not be cut = atom
• Word origin a- + -tom
  not + cut
• Democritus championed atoms

“Nothing exists except atoms and empty space; everything else is opinion.” - Democritus 460–370 B.C.
Dalton’s Atomic Theory (1808)

1. Each element is composed of tiny, indestructible particles called atoms.
2. All atoms of an element are identical in mass, size, and chemical properties. Atoms of different element are different.
3. Compounds are atoms joined together in small whole number ratios.
4. Chemical reactions rearrange atoms to new compounds, but no atoms are lost.
Dalton’s Atomic Theory

• Explains law of conservation of mass
• Explains law of definite composition for compounds
• Explains the whole number ratios of chemical formulas.
• All four points of the theory have exceptions.
• Theory was important to guide thinking about atoms
Modern Evidence for Atoms
Using a Scanning Tunneling Microscope
to Move Atoms (the Cones in the Figure)

Figure 4.2 The letters IBM spelled out with atoms on a surface.
Sizes of Atoms

• Dalton determined the relative mass of atoms.
  ✓ Mass of a H atom = 1 amu (atomic mass unit).
    ➢ Modern scale mass of C-12 atom = 12 amu exactly.

• Sizes of atoms in metric units
  ✓ Mass of H atom = $1.67 \times 10^{-24}$ g.
  ✓ Volume of H atom = $2.1 \times 10^{-25}$ cm$^3$. 
Some Notes on Charges

- Opposite charges attract.
  - ✓ + attracted to –.

- Like charges repel.
  - ✓ + repels +.
  - ✓ – repels –.

- Neutral means # of positive charges = # of negative charges

- Atoms are neutral.

Figure 4.7 illustrating the attraction of opposite charges.

Also the repulsion of like Charges.
The Atom Is Divisible

- J. J. Thomson discovered the electron.
- Electrons carry a negative charge.
- The mass of the electron is $1/1836^{\text{th}}$ the mass of a hydrogen atom.
- There must be a positive part of an atom because atoms are neutral.
4.3 The Nuclear Atom
Thomson’s Plum Pudding Atom
(Modern Version Chocolate Chip Cookie)

Figure 4.3 and Figure 4.5(a) the picture of the plum pudding model of the atom. A large volume of positive charge and a tiny electron embedded in the sphere of Positive charge.
Rutherford’s Experiment

• How can you prove something is empty?
• Used thin sheets of gold as target
• Bullet = alpha particles mass 4 amu, charge +2
• Behavior of alpha particle interacting with gold to explain structure
Rutherford’s Experiment

Figure 4.4 showing the set up of the Rutherford gold foil Bombardment experiment.
Of the Alpha Particle Shot at Gold

- 98% → went straight through.
- 2% → deflected by large angles.
- 0.01% → bounced off the gold foil.

Rutherford was surprised:

✓ “...As if you fired a 15”-canon shell at a piece of tissue paper and it came back and hit you.”
Rutherford’s Conclusions

- Atom mostly empty space.
- Atom contains a dense particle of positive charge.
- Small in volume, but most of the atom’s mass.
- He called the particle the nucleus.
Figure 4.5 (a) shows the expected results for the plum pudding model.
(b) The revised model based on the actual results of the experiment which were explained by the nuclear model. A small concentrated positive charge at the center of the atom.
Rutherford’s Interpretation—
The Nuclear Model

1. **Nucleus.**
   1. 1/10 trillionth the volume of the atom.
   2. Most of the mass of the atom
   3. Positive charge to balance electrons.
   4. Electrons spread out around the nucleus.
Structure of the Nucleus

• Rutherford proposed a particle called a proton with the same amount of charge as an electron but opposite sign.

• Mass of proton = 1 amu

• For the atom to be neutral, there must be equal numbers of protons and electrons.
Some Problems

• Atoms with more than one proton have positive charges together? (They should repel.)

• Consider a beryllium atom:
  • It has 4 protons, then it should weigh 4 amu.
  • Actually mass 9.01 amu!

✓ Remember: The electron’s mass is only about 0.00055 amu.
There Must Be Something Else There

- Rutherford proposed that there was another particle in the nucleus—it is called a \textbf{neutron} (1 amu, but no charge).
The Modern Atom

• Protons, neutrons, and electrons.
• Nucleus: protons and neutrons.
• Average diameter of nucleus \(10^{-13}\) cm.
• Average diameter of atom \(10^{-8}\) cm.
  
  Diameter of an atom is \(10^5\) times larger than the diameter of the nucleus.
4.4 The Properties of Protons, Neutron, and Electrons
Properties of Subatomic Particles

Table 4.1 The properties of the three subatomic particles. protons ($p^+$) electron ($e^-$) and neutrons ($n^0$).

The symbols are not in the table. They are shown in parentheses above.
4.5 Elements: Defined by the Number of Protons
Elements

• The number of protons defines the element
  ✓ All carbon atoms have 6 protons in their nuclei.

• The number of protons in the nucleus is the atomic number. (symbol Z).

• Elements of Periodic Table are in order of their atomic numbers.

• Elements can be identified by a one or two letter symbol.

• Elements you need to memorize are on the class web site.
4.6 Looking for Patterns: The Periodic Law and the Periodic Table
The Periodic Table of Elements

Figure 4.9 The modern periodic table of the elements. The information shown in most tables includes:
- Atomic number
- Chemical symbol
- Atomic mass (more of this at the end of the chapter)
Mendeleev

- Ordered elements by atomic mass.
- Saw a repeating pattern of properties.
- **Periodic law**—When the elements are arranged in order of increasing relative mass, certain sets of properties recur periodically?
- He predict properties of undiscovered elements.
- Some elements were out of order by mass
  ✓ Te & I
The figure presented in class was not easy to interpret. I have simplified it here. The hydrogen compounds that are formed by the first 17 elements excluding noble gases show a periodic pattern.

<table>
<thead>
<tr>
<th>Element</th>
<th>Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>H₂</td>
</tr>
<tr>
<td>Li</td>
<td>LiH</td>
</tr>
<tr>
<td>Be</td>
<td>BeH₂</td>
</tr>
<tr>
<td>B</td>
<td>(BH₃)ₙ</td>
</tr>
<tr>
<td>C</td>
<td>CH₄</td>
</tr>
<tr>
<td>N</td>
<td>NH₃</td>
</tr>
<tr>
<td>O</td>
<td>H₂O</td>
</tr>
<tr>
<td>F</td>
<td>HF</td>
</tr>
<tr>
<td>Na</td>
<td>NaH</td>
</tr>
<tr>
<td>Mg</td>
<td>MgH₂</td>
</tr>
<tr>
<td>Al</td>
<td>(AlH₃)ₙ</td>
</tr>
<tr>
<td>Si</td>
<td>SiH₄</td>
</tr>
<tr>
<td>P</td>
<td>PH₃</td>
</tr>
<tr>
<td>S</td>
<td>H₂S</td>
</tr>
<tr>
<td>Cl</td>
<td>HCl</td>
</tr>
</tbody>
</table>

The n for BH₃ and AlH₃ means those structure form a long chain of connected atoms.
Mendeleev's Predictions for Ekasilicon (Germanium)

<table>
<thead>
<tr>
<th>Property</th>
<th>Silicon’s props</th>
<th>Tin’s props</th>
<th>Predicted value</th>
<th>Measured value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atomic mass</td>
<td>28</td>
<td>118</td>
<td>72</td>
<td>72.6</td>
</tr>
<tr>
<td>Color</td>
<td>Gray</td>
<td>White metal</td>
<td>Gray</td>
<td>Gray-white</td>
</tr>
<tr>
<td>Density</td>
<td>2.32</td>
<td>7.28</td>
<td>5.5</td>
<td>5.4</td>
</tr>
<tr>
<td>Reaction with acid and base</td>
<td>Resists acid, reacts base</td>
<td>Reacts acid, resists base</td>
<td>Resists both</td>
<td>Resists both</td>
</tr>
<tr>
<td>Oxide</td>
<td>SiO$_2$</td>
<td>SnO$_2$</td>
<td>Eks$_1$O$_2$</td>
<td>GeO$_2$</td>
</tr>
</tbody>
</table>
Ways of Dividing the Table

- Metals, nonmetals and metalloids
- Groups or families (columns) and periods (rows).
- Representative elements and transition metals
- Special names for groups:
  - ✓ Alkali metals (1A) ✓ Halogens (7A)
  - ✓ Alkaline earths (2A) ✓ Noble gases (8A)
Periodicity

- Blue = Metal
- Green = Metalloid
- Red = Nonmetal
Periodicity

A figure similar to Figure 4.12 showing the locations of metals non-metals, and metalloids.

Metals – lower left
Non-metals – upper right
Metalloids – border elements usually shown by a stair step that runs under the elements B, Si, As, Te, and At.
Metals

- Solids at room temperature, except Hg.
- Shiny.
- Conduct heat.
- Conduct electricity.
- Malleable = Can be shaped.
- Ductile = Drawn or pulled into wires.
- Lose electrons and form cations (positive ions) in reactions.
- About 75% of the elements.
- Lower left on the table.

Mercury – a liquid metal

Sodium – a soft reactive metal that can be cut with a butter knife.
Nonmetals

- All 3 states of matter.
- Poor conductors of heat.
- Poor conductors of electricity.
- Solids are brittle.
- Gain electrons in reactions to become anions (negative ions).
- Upper right on the table.
  ✓ Except H.

Chlorine – a green gas that is toxic.
Metalloids

• Show some of the properties of metals and some of nonmetals.

• Also known as semiconductors. Properties of Silicon:
  ✓ Shiny ≈ metal
  ✓ Conducts electricity ≈ metal
  ✓ Does not conduct heat well ≈ nonmetal
  ✓ Brittle ≈ nanmetal

Silicon – similar to page 100. Silicon wafers are used to make computer chips.
The Modern Periodic Table

- Elements with similar chemical and physical properties are in the same column called **Groups** or **Families**.
  - Number + a letter
  - “A” are the main group or representative elements.
  - “B” groups are the transition elements.
  - IUPAC uses 1-18 numbering.

- Rows are called **Periods**.
Numbering system for Groups

• USA – Main groups (first 2 columns and last 6 columns) are A groups. Transition metals (middle columns) are B groups.
• Europe – Main groups - first 2 columns are A and last 6 columns are B groups. Transition metals have both A and B groups.
• IUPAC – compromise Columns 1-18 from left to right.
Periodic table supplied with each quiz (USA and IUPAC numbers)

<table>
<thead>
<tr>
<th>Group</th>
<th>Periodic Table of the Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>H 1.0079</td>
</tr>
<tr>
<td>2</td>
<td>Li 6.941</td>
</tr>
<tr>
<td>3</td>
<td>Be 9.0122</td>
</tr>
<tr>
<td>4</td>
<td>Mg 24.305</td>
</tr>
<tr>
<td>5</td>
<td>Na 22.990</td>
</tr>
<tr>
<td>6</td>
<td>K 39.108</td>
</tr>
<tr>
<td>7</td>
<td>Ca 40.078</td>
</tr>
<tr>
<td>8</td>
<td>Sc 44.955</td>
</tr>
<tr>
<td>9</td>
<td>Ti 47.867</td>
</tr>
<tr>
<td>10</td>
<td>V 50.942</td>
</tr>
<tr>
<td>11</td>
<td>Cr 52.005</td>
</tr>
<tr>
<td>12</td>
<td>Mn 54.938</td>
</tr>
<tr>
<td>13</td>
<td>Fe 55.845</td>
</tr>
<tr>
<td>14</td>
<td>Co 58.933</td>
</tr>
<tr>
<td>15</td>
<td>Ni 63.546</td>
</tr>
<tr>
<td>16</td>
<td>Cu 65.391</td>
</tr>
<tr>
<td>17</td>
<td>Zn 69.723</td>
</tr>
<tr>
<td>18</td>
<td>Ga 72.611</td>
</tr>
<tr>
<td>19</td>
<td>Ge 74.922</td>
</tr>
<tr>
<td>20</td>
<td>As 77.926</td>
</tr>
<tr>
<td>21</td>
<td>Se 79.904</td>
</tr>
<tr>
<td>22</td>
<td>Br 83.80</td>
</tr>
<tr>
<td>23</td>
<td>Kr 85.468</td>
</tr>
<tr>
<td>24</td>
<td>Sr 87.62</td>
</tr>
<tr>
<td>25</td>
<td>Y 91.224</td>
</tr>
<tr>
<td>26</td>
<td>Zr 92.906</td>
</tr>
<tr>
<td>27</td>
<td>Nb 95.94</td>
</tr>
<tr>
<td>28</td>
<td>Mo 98.906</td>
</tr>
<tr>
<td>29</td>
<td>Tc 101.07</td>
</tr>
<tr>
<td>30</td>
<td>Ru 102.91</td>
</tr>
<tr>
<td>31</td>
<td>Rh 106.42</td>
</tr>
<tr>
<td>32</td>
<td>Pd 107.87</td>
</tr>
<tr>
<td>33</td>
<td>Ag 111.82</td>
</tr>
<tr>
<td>34</td>
<td>Cd 114.82</td>
</tr>
<tr>
<td>35</td>
<td>In 118.71</td>
</tr>
<tr>
<td>36</td>
<td>Sn 121.76</td>
</tr>
<tr>
<td>37</td>
<td>Sb 125.79</td>
</tr>
<tr>
<td>38</td>
<td>Te 127.60</td>
</tr>
<tr>
<td>39</td>
<td>I 131.29</td>
</tr>
<tr>
<td>40</td>
<td>Xe 131.92</td>
</tr>
<tr>
<td>41</td>
<td>Cs 132.91</td>
</tr>
<tr>
<td>42</td>
<td>Ba 137.33</td>
</tr>
<tr>
<td>43</td>
<td>La 138.91</td>
</tr>
<tr>
<td>44</td>
<td>Hf 178.49</td>
</tr>
<tr>
<td>45</td>
<td>Ta 180.95</td>
</tr>
<tr>
<td>46</td>
<td>W 183.84</td>
</tr>
<tr>
<td>47</td>
<td>Re 186.21</td>
</tr>
<tr>
<td>48</td>
<td>Os 190.23</td>
</tr>
<tr>
<td>49</td>
<td>Ir 192.22</td>
</tr>
<tr>
<td>50</td>
<td>Pt 195.08</td>
</tr>
<tr>
<td>51</td>
<td>Au 196.97</td>
</tr>
<tr>
<td>52</td>
<td>Hg 200.59</td>
</tr>
<tr>
<td>53</td>
<td>Tl 204.38</td>
</tr>
<tr>
<td>54</td>
<td>Pb 207.2</td>
</tr>
<tr>
<td>55</td>
<td>Bi 208.98</td>
</tr>
<tr>
<td>56</td>
<td>Po 209.98*</td>
</tr>
<tr>
<td>57</td>
<td>At 222.02*</td>
</tr>
<tr>
<td>58</td>
<td>Fr 223.02</td>
</tr>
<tr>
<td>59</td>
<td>Ra 226.03*</td>
</tr>
<tr>
<td>60</td>
<td>Ac 227.03*</td>
</tr>
<tr>
<td>61</td>
<td>Ce 140.12</td>
</tr>
<tr>
<td>62</td>
<td>Pr 140.91</td>
</tr>
<tr>
<td>63</td>
<td>Nd 143.92</td>
</tr>
<tr>
<td>64</td>
<td>Sm 150.36</td>
</tr>
<tr>
<td>65</td>
<td>Eu 151.96</td>
</tr>
<tr>
<td>66</td>
<td>Gd 157.25</td>
</tr>
<tr>
<td>67</td>
<td>Tb 158.93</td>
</tr>
<tr>
<td>68</td>
<td>Dy 162.50</td>
</tr>
<tr>
<td>69</td>
<td>Ho 164.93</td>
</tr>
<tr>
<td>70</td>
<td>Er 167.26</td>
</tr>
<tr>
<td>71</td>
<td>Tm 168.93</td>
</tr>
<tr>
<td>72</td>
<td>Yb 173.04</td>
</tr>
<tr>
<td>73</td>
<td>Lu 174.97</td>
</tr>
</tbody>
</table>

*Note: Atomic masses shown here are the 1993 IUPAC values with a maximum of five significant figures (T. B. Coplen et al., Inorg. Chim. Acta 1994, 217, 217). An asterisk indicates the mass of a commonly known radioisotope. Numbers in parentheses are the mass numbers of the corresponding longer-lived isotope.
Special Names for Groups and Regions of the Table

• Learn the names of the regions of the periodic table shown at the top and bottom of Page 102.
Important Groups—Hydrogen

• Nonmetal.
• Colorless, diatomic gas, H₂.
  ✓ Very low melting point and density.
• Form molecular compounds with nonmetals.
  ✓ HCl is an acidic gas.
  ✓ H₂O is a liquid.
  ✓ CH₄ methane is a fuel in natural gas.
• Reacts with metals to form ionic hydrides, NaH
  ✓ NaH
  ✓ CaH₂.
Important Groups—Alkali Metals

- Group IA = Alkali metals.
- Soft, low melting points, low density.
- Very reactive, violently reaction with water.
  \[ 2 \text{Na} + 2 \text{H}_2\text{O} \rightarrow 2 \text{NaOH} + \text{H}_2 \]
- Potassium at periodic table of videos
- Tend to form water soluble compounds
Important Groups—Alkali Earth Metals

- Group IIA = Alkali earth metals.

- Harder, higher melting, and denser than alkali metals.
  - Mg alloys used as structural materials.

Magnesium at the periodic table of videos

- Reactive, but less than corresponding alkali metal.

- Reactivity with water to form H₂:
  - Be = none, Mg = steam, Ca, Sr, Ba = cold water.
Important Groups—Halogens

- Group VIIA = Halogens.
- Nonmetals.
- \( \text{F}_2 \) and \( \text{Cl}_2 \) gases, \( \text{Br}_2 \) liquid, and \( \text{I}_2 \) solid.
- Very reactive
  
  **Bromine at the periodic table of videos**

- React with metals to form ionic compounds.

- Hydrogen halides all acids:
  - HF weak < HCl < HBr < HI.
Important Groups—Noble Gases

• Group VIIIA = Noble gases.
• All gases at room temperature.
• Very unreactive, practically inert.

Noble gases shown on Page 102 bottom right.
4.7 Ions: Losing or Gaining Electrons
Charged Particles

• In a chemical change, the number of protons in the nucleus of the atom doesn’t change. (Nuclear reactions can change the number of protons. We will not be concerned with nuclear reactions.)

• Atoms can gain or lose electrons to become electrically charged, these particles are called ions.
Ions

• Only gaining or losing electrons is possible, not protons.
• Ion charge = # protons − # electrons.
• Atoms that lose electrons get a positive charge and become cations.
• Atoms that gain electrons get a negative charge and become anions.
• Chemically, ions are much different than the neutral atoms.

• Cations are pawsitive.  >^..^<
Atomic Structures of Ions

- Nonmetals form anions by gaining electrons.

<table>
<thead>
<tr>
<th>Cl atom</th>
<th>Cl(^-) ion</th>
<th>S atom</th>
<th>S(^2-) ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 p(^+)</td>
<td>17 p(^+)</td>
<td>16 p(^+)</td>
<td>16 p(^+)</td>
</tr>
<tr>
<td>17 e(^-)</td>
<td>18 e(^-)</td>
<td>16 e(^-)</td>
<td>18 e(^-)</td>
</tr>
<tr>
<td>neutral</td>
<td>17-18 = -1</td>
<td>neutral</td>
<td>16-18 = -2</td>
</tr>
</tbody>
</table>

- Anions are named by changing the ending of the name to \(-\text{id}e\).

  fluorine \( F + 1e^- \rightarrow F^- \) fluoride ion
  oxygen \( O + 2e^- \rightarrow O^{2-} \) oxide ion

- Each added electron adds one negative charge.
Atomic Structures of Ions

- Metals form cations by losing electrons.

<table>
<thead>
<tr>
<th>K atom</th>
<th>K⁺ ion</th>
<th>Mg atom</th>
<th>Mg²⁺ ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 p⁺</td>
<td>19 p⁺</td>
<td>12 p⁺</td>
<td>12 p⁺</td>
</tr>
<tr>
<td>19 e⁻</td>
<td>18 e⁻</td>
<td>12 e⁻</td>
<td>10 e⁻</td>
</tr>
<tr>
<td>neutral</td>
<td>19-18= +1</td>
<td>neutral</td>
<td>12-10= +2</td>
</tr>
<tr>
<td>potassium atom</td>
<td>potassium ion</td>
<td>magnesium atom</td>
<td>magnesium ion</td>
</tr>
</tbody>
</table>

- Cations are named the same as the metal.

  sodium   \( \text{Na} \rightarrow \text{Na}⁺ + 1\text{e}⁻ \)   sodium ion
  calcium  \( \text{Ca} \rightarrow \text{Ca}²⁺ + 2\text{e}⁻ \)   calcium ion

- Each added electron adds one unit of negative charge.
Determine the number of protons in
a) Fe$^{3+}$
b) P$^{3-}$
Determine the number of protons in
a) $\text{Fe}^{3+}$
b) $\text{P}^{3-}$

- Fe is iron element #26.
  - $Z = 26 = \#p^+\#s = \#e^-\#s$ in neutral atom
  - 3+ charge means 3 electrons lost $26 - 3 = 23$ e$^-$

- P is phosphorus element #15.
  - $Z = 15 = \#p^+\#s = \#e^-\#s$ in neutral atom
  - 3- charge means 3 electrons gained $15 + 3 = 18$ e$^-$
Valence Electrons and Ion Charge

• The highest energy electrons are the valence electrons.

• The number of valence electrons = group number for the representative elements
  ✓ Na, 1A, 1 valence electron
  ✓ O, 6A, 6 valence electrons
Ions of Main Group Elements

• Main group metals loses electrons to form a cation with the same number of electrons as the previous noble gas.
  \[ \text{Li}^+ = 2 \text{e}^- = \text{He}; \quad \text{Al}^{3+} = 10 \text{e}^- = \text{Ne}. \]

• Nonmetals gain electron to form anions with the same number of electrons as the next noble gas
  \[ \text{Cl}^- = 18 \text{e}^- = \text{Ar}; \quad \text{Se}^{2-} = 36 \text{e}^- = \text{Kr}. \]
Ion Charge and the Periodic Table

• The periodic table may be used to determine charge expected for an ion.

• For many main group metals, the cation charge = the group number.

• For nonmetals, the anion charge = the group number − 8.
• Periodic Table and charge of ion formed
4.8 Isotopes: When the Number of Neutrons Varies
Structure of the Nucleus

• Soddy discovered that an element could have atoms with different masses called isotopes.
  ✓ Chlorine has two primary isotopes
    ➢ one has a mass of about 35 amu
    ➢ another with a mass of about 37 amu.

• Any sample of Cl will be a mixture of these two isotopes.

• Average mass of a Cl atom is a weighted average of all the isotopes
  ✓ The atomic mass of chlorine is 35.45 amu.
Atomic symbol for an Isotope

• Isotopes are represented by a chemical symbol. $^A_ZX$
  • $X$ is the chemical symbol.
  • $Z$ is the atomic number.
  • $A$ is the mass number
• Another common notation is:

Name-$A$ or $X-A$,
Examples: Chlorine-$35$, Carbon-$14$, Hydrogen-$2$ or $\text{Cl-35}$, $\text{C-14}$, or $\text{H-2}$
Isotopes

• Chemically identical.
• All isotopes of an element have the same number of protons.
• Different masses of isotopes are due to differing number of neutrons.
• Isotopes are identified by their mass numbers (A).
  ✓ Protons + neutrons.
Isotopes, Continued

- Atomic Number (Z) = number of protons.
- Mass Number (A) = \( \text{Protons} + \text{Neutrons} \).
- Atomic mass is NOT the mass number

✓ Percent natural abundance = Relative amount found in a sample.

✓ Example

Neon:

Figure 4.15 showing the distribution of neon isotopes.
Isotopes

- How many neutrons are there in Cl-35 and Cl-37
- Mass number = protons + neutrons
- Atomic number = protons
- Mass number – atomic number = neutrons

\[
\begin{align*}
\text{Cl }^{35} & \quad A = 35, \ Z = 17, \ A - Z = 35 - 17 = 18, \ \text{so} \\
\text{Cl }^{37} & \quad A = 37, \ Z = 17, \ A - Z = 37 - 17 = 20 \ \text{neutrons}
\end{align*}
\]
### Practice—Complete the Following Table.

<table>
<thead>
<tr>
<th></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>Calcium-40</td>
<td>20</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon-13</td>
<td>6</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminum-27$^{+3}$</td>
<td>13</td>
<td>27</td>
<td>13</td>
<td>13</td>
<td>14</td>
</tr>
</tbody>
</table>
## Practice—Complete the Following Table, Continued.

<table>
<thead>
<tr>
<th></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>Calcium-40</td>
<td>20</td>
<td>40</td>
<td>20</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Carbon-13</td>
<td>6</td>
<td>13</td>
<td>6</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>Aluminum-27$^{+3}$</td>
<td>13</td>
<td>27</td>
<td>13</td>
<td>10</td>
<td>14</td>
</tr>
</tbody>
</table>
4.9 Atomic mass
Average Atomic Mass

The average atomic mass is an average that takes into account the percentages of each isotope.

\[
\text{Average Atomic Mass} = \left( \text{fraction of isotope 1} \times \frac{\text{mass of isotope 1}}{\text{isotope 1}} \right) + \left( \text{fraction of isotope 2} \times \frac{\text{mass of isotope 2}}{\text{isotope 2}} \right) + \ldots
\]

Note: relative abundances are usually given in percentages. To convert to a fraction divide the percentage by 100.
# Neon

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Number of protons</th>
<th>Number of neutrons</th>
<th>A, mass number</th>
<th>Percent natural abundance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ne-20 or $^{20}_{10}\text{Ne}$</td>
<td>10</td>
<td>10</td>
<td>20</td>
<td>90.48%</td>
</tr>
<tr>
<td>Ne-21 or $^{21}_{10}\text{Ne}$</td>
<td>10</td>
<td>11</td>
<td>21</td>
<td>0.27%</td>
</tr>
<tr>
<td>Ne-22 or $^{22}_{10}\text{Ne}$</td>
<td>10</td>
<td>12</td>
<td>22</td>
<td>9.25%</td>
</tr>
</tbody>
</table>
Calculation for Neon

Average atomic mass = (0.9048)x(20 amu) + (0.0027)x(21 amu) + 
+ (0.0925)x(22 amu)
= 20.19 amu

Note the true value is 20.18 amu. The difference is because the isotopes masses are not exactly 20, 21, and 22 amu. When the exact masses of the isotopes are used, the value in the periodic table will be obtained.
A More Exact Calculation using the Exact Masses of the Isotopes

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Abundance</th>
<th>Mass (amu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ga-69</td>
<td>60.11 %</td>
<td>68.9256</td>
</tr>
<tr>
<td>Ga-71</td>
<td>39.89 %</td>
<td>70.9247</td>
</tr>
</tbody>
</table>

Average Atomic Mass = (0.6011)x(68.9256 amu) + (0.3989)x(70.9247 amu) 
= 69.72 amu
Mass Number Is Not the Same as Atomic Mass

• The atomic mass is an experimental number determined from all naturally occurring isotopes.

• The mass number refers to the number of protons + neutrons in one atom.