Chapter 2: Atoms and Elements
Early Ideas about the structure of Matter

• Ancient Greece
  • Leucippus and Democritus: Proposed that there were many types of atoms, different in shape and size.
  • Aristotle: Substances have no “smallest part”, but were made of earth, air, fire, and water.
  • Aristotle wins because of his influence, and the idea of atoms is tabled for nearly 2000 years.
Early Ideas about the structure of Matter

– Lavoisier: Law of Conservation of Mass
  *In a chemical reaction, matter is neither created nor destroyed.*

– Proust: Law of Definite Proportions
  *All samples of a given compound, regardless of their source or how they were prepared, have the same proportions of their constituent elements.*

– Dalton: Law of Multiple Proportions
  *When two elements (A and B) form two different compounds, the masses of element B that combine with element A can be expressed as a ratio of small whole numbers.*
Dalton: Atomic Theory of Matter

Matter is composed of atoms

Atoms of given element have identical properties

Different elements have different properties

Atoms combine in whole number ratios
Cathode Ray Tube

J. J. Thomson
Charge to Mass Ratio of electrons
Cathode Ray Tube

- [Link](http://www.chem.uiuc.edu/clcwebsite/video/Cath.wmv)
Oil Drop Experiment

Robert Millikan
Charge and Mass of electrons

Positively charged plate
Ionizing radiation
Light source
Negatively charged plate

Charged oil droplets are suspended in electric field.

Atomizer
Viewing microscope
Ernest Rutherford
The structure of the atom

Most $\alpha$ particles pass through with little or no deflection.

A few $\alpha$ particles are deflected through large angles.
Composition of Atoms

Atoms contain protons, neutrons, and electrons

The nucleus includes protons and neutrons

Electrons surround the nucleus

Protons have positive (+) charge

Electrons have negative (−) charge

Neutrons have no charge
Isotopes

Atoms with the same atomic number but different masses are called isotopes

Since the chemical behavior of atoms is determined by electrostatic attraction between the nuclei and the electrons, atoms with the same number of protons (Z) behave identically

\[ ^{81}\text{Br} \text{ and } ^{79}\text{Br} \quad \text{not } ^{81}\text{Kr} \text{ and } ^{81}\text{Br} \]
Isotope Symbol

Mass Number = number of protons + number of neutrons

Atomic Number = number of protons

Elemental Symbol
Isotopes Mark The Spot
Ratios of stable isotopes help locate the origin of corpses, follow migration routes, and authenticate items as different as bottled water and expensive cheese.

The term isoscape was first coined by Jason West, now an ecologist at Texas A&M University. (pubs.acs.org/cen/science/89/8926sci1.html)
Atomic Mass

Atoms have measurable masses

The Atomic Mass of an element is the average mass of an atom of the element

Units:
1 amu = 1.66 x10^{-27} kg

\[
\text{Atomic Mass} = \left( \frac{\% \text{ abundance of isotope 1}}{100} \right) \times \text{mass of isotope 1} \\
+ \left( \frac{\% \text{ abundance of isotope 2}}{100} \right) \times \text{mass of isotope 2} \ldots +
\]
76. An element has four naturally occurring isotopes with the masses and natural abundances given here. Find the atomic mass of the element and identify it.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Mass (amu)</th>
<th>Abundance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>135.90714</td>
<td>0.19</td>
</tr>
<tr>
<td>2</td>
<td>137.90599</td>
<td>0.25</td>
</tr>
<tr>
<td>3</td>
<td>139.90543</td>
<td>88.43</td>
</tr>
<tr>
<td>4</td>
<td>141.90924</td>
<td>11.13</td>
</tr>
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Isotopes and Mass Spectrometry

Atomic mass and isotopic abundance can be experimentally measured using mass spectrometer – highly accurate mass/charge ratio measurement allows the accurate identification of atom or molecules.
Example

• Use the abundances and masses of the isotopes from the previous example to predict what the mass spectrum of that element would look like:

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The Periodic Table of the Elements
The Periodic Table of the Elements

Dmitri Mendeleev
Sodium

11

Na

22.9898

Atomic Number
Symbol
Atomic Weight
The Periodic Table of the Elements

<table>
<thead>
<tr>
<th>Main Group Elements</th>
<th>Transition Elements</th>
</tr>
</thead>
</table>

- **Main Group Elements** are located in the lower left and upper right sections of the periodic table.
- **Transition Elements** are found in the middle section of the periodic table.
The Periodic Table of the Elements

Main Group Metals
Transition Metals
Nonmetals
Metalloids
Elements that Exist as Diatomic or Triatomic Molecules
Allotropes

One interesting aspect of the nonmetals (like carbon) is that an element of this type can often exist in several different and distinct forms, called allotropes.

Each allotrope has its own physical and chemical properties.
Ions

Ions are atoms or groups of atoms with electric charge

*Cations* have positive charge

*Anions* have negative charge
Monatonic Cations

Formed from neutral atoms by removing one or more electrons

Metals, often from the first 2 columns of the periodic table

\[ \text{Na} \rightarrow \text{Na}^+ + \text{e}^- \]

\[ \text{Mg} \rightarrow \text{Mg}^{2+} + 2\text{e}^- \]
Monatomic Ions

1A: +1 cations

- H⁺ (Hydrogen)
- Li⁺ (Lithium)
- Na⁺ (Sodium)
- K⁺ (Potassium)
- Rb⁺ (Rubidium)
- Cs⁺ (Cesium)
Monatomic Ions

2A: +2 cations

Main Group 1A, 2A
M^{n+} where n=group number

Naming: Element + ‘cation’
Monatonic Cations

Cations are smaller than their parent atoms.
Monatomic Anions

Formed from neutral atoms by adding one or more electrons

Nonmetals, often halogens from the last 2 columns of the periodic table

\[ \text{Cl} + e^- \rightarrow \text{Cl}^- \]

\[ \text{O} + 2e^- \rightarrow \text{O}^{2-} \]
Monatomic Ions

7A: -1 anions

H⁺
F⁻
Cl⁻
Br⁻
I⁻
Monatomic Ions

6A: -2 anions

O^{2-}
S^{2-}
Se^{2-}
Te^{2-}
### Monatomic Ions

#### Naming Monatomic Anions

<table>
<thead>
<tr>
<th>$C^4-$, carbide</th>
<th>$N^3-$, nitride</th>
<th>$O^2-$, oxide</th>
<th>$F^-$, fluoride</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$S^2-$, sulfide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$Cl^-$, chloride</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$Br^-$, bromide</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$I^-$, iodide</td>
<td></td>
</tr>
</tbody>
</table>

Name derived by adding “ide” suffix.
Monatomic Anions

Anions are larger than their parent atoms.
The Mole

1 mol items = 6.022 x 10^{23} items

• Avogadro’s number is the number of $^{12}$C atoms in exactly 12 grams.

Atomic Mass:

1 atom of H = 1.01 amu
1 mol of H = 1.01 grams

CONVERSION FACTOR ALERT!

The periodic table is full of conversion factors that take us from mass to moles of ANY atom.
Example

• Which sample has the most atoms?

20 grams of Pt or 10 grams of Cu