The Atomic Nucleus & Radioactive Decay  
(Chapter 10)

Student Learning Outcomes

* Analyze radioactive decay and its results
* Differentiate between nuclear fission and fusion

Major Constituents of an Atom

<table>
<thead>
<tr>
<th>Particle (symbol)</th>
<th>Charge (C)</th>
<th>Electronic Charge</th>
<th>Mass (u)</th>
<th>Mass (u)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron (e)</td>
<td>-1.60 × 10⁻¹⁹</td>
<td>-1</td>
<td>9.109 × 10⁻³¹</td>
<td>0.00055</td>
<td>Outside nucleus</td>
</tr>
<tr>
<td>Proton (p)</td>
<td>1.60 × 10⁻¹⁹</td>
<td>+1</td>
<td>1.672 × 10⁻²⁴</td>
<td>1.6725</td>
<td>Nucleus</td>
</tr>
<tr>
<td>Neutron (n)</td>
<td>0.00</td>
<td>0</td>
<td>1.675 × 10⁻²⁴</td>
<td>1.6894</td>
<td>Nucleus</td>
</tr>
</tbody>
</table>

U=unified atomic mass units

https://www.youtube.com/watch?v=YQP4UJhNn0I
How do we know the number of particles in the nucleus?

- **Atomic number**: protons (periodic table)
- **Mass number**: protons + neutrons
- Ions (net charge) and isotopes (different mass numbers) maintain the same chemical identity as regular atoms.

Example: $^{17}_{8}$O$^{-2}$

### Carbon Isotopes - Example

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Protons (Z)</th>
<th>Neutrons (N)</th>
<th>Mass # (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{12}$C</td>
<td>6</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>$^{13}$C</td>
<td>6</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>$^{14}$C</td>
<td>6</td>
<td>8</td>
<td>14</td>
</tr>
</tbody>
</table>
Three Isotopes of Hydrogen

In naturally occurring Hydrogen - 1 atom in 6000 is deuterium and 1 in 10,000,000 is tritium. Heavy water = D$_2$O

Practice

How many protons, and how many neutrons, does each contain? Is it an isotope? Is it an ion?

$^3_2$He $^{13}_6$C $^{34}_{17}$Cl $^{26}_{13}$Al $^{6}_{3}$Li$^+$

What is the limit for the Strong Nuclear Force?

- The protons and neutrons in the core of an atom are held together by the strong nuclear force.

- **Limit**: Size of diameter $<$ 10^{-15} m

- The strong nuclear force balances the electric force in a stable atom.

<table>
<thead>
<tr>
<th>Strong Nuclear Force</th>
<th>Electric Force</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attraction</td>
<td>Repulsion</td>
</tr>
<tr>
<td>Protons &amp; Neutrons</td>
<td>Protons</td>
</tr>
<tr>
<td>Range $&lt;$ 10^{15} m</td>
<td>Range $&gt;$ 10^{15} m</td>
</tr>
</tbody>
</table>
Practice

1) Would a helium (He) atom or a bismuth (Bi) atom tend to be more unstable?

2) What about a $^3_2$He atom?

What does radioactivity mean?

- Radioactivity is the transformation of an unstable atom into a different type of atom.
- Over 60 radioactive elements can be found in nature.
- There are 3 general sources of radioactivity.
  - Earth
  - Cosmic Rays
  - Human Produced

https://www.youtube.com/watch?v=TJgc28csgv0

How do we determine the new isotope?

- Atoms radioactively decay by emitting particles.
- **Alpha radiation**: $(\text{He}^+)\) is a positively charged particle that leaves the nucleus.
  
  ![Alpha radiation diagram]

  Can cause damage on the surface of matter
Gamma Rays: (\(\gamma\)) are high energy photons.

The Rules

<table>
<thead>
<tr>
<th>Unstable Condition</th>
<th>Name</th>
<th>Particle</th>
<th>Charge</th>
<th>Symbol</th>
<th>Rule</th>
</tr>
</thead>
</table>
| 83+ Protons         | Alpha | \(\alpha\)He | +2     | \(\beta^+\) | Mass # = 4  
|                    |       |          |        |        | Atomic # = 2                |
| Neutron/Proton Ratio | Beta | e−      | −1     | \(\beta^−\) | Mass # = 0  
|                    |       |          |        |        | Atomic # = 1                |
| Excited Nucleus    | Gamma | 0        |        | \(\gamma\) | No Change                  |
Practice
What is the new isotope?

1. $^{226}_{88}\text{Ra} \rightarrow X + e^-$
2. $^{226}_{88}\text{Ra} \rightarrow X + \square$
3. $^{222}_{86}\text{Rn} \rightarrow X + ^{4}_2\text{He}$
4. $^{14}_6\text{C} \rightarrow X + \square$

What does the half-life of an element indicate?

- Half-life is the time it takes for one half of an unstable substance to decay into a different substance. (radiometric dating)
  - Shorter half-life = more disintegrations/second
  - Longer half-life = fewer disintegrations/second
Practice

1. An isotope of radium (Ra) has a half-life of 1620 years. If 1000 grams were placed in a barrel, how much of the material in the barrel would be radium after 6480 years?

2. $^{225}_{89}$Ac (Actinium) has a half-life of 10.0 days. How many days would it take to decrease the original amount placed in a barrel to $1/8$th of the original amount?

What is carbon dating?

- Carbon dating is the process of using the known half-life of carbon to determine when something died.

$$^{14}_6C \rightarrow ^{14}_7N + \gamma$$

- Living plants and animals take in $^{12}C$(Carbon-14)
- Carbon-14 is a radioactive isotope
Practice

The half-life of carbon-14 is 5730 years.

1. If a piece of wood has 1/2 as much carbon-14 as compared to a living tree, how old is the wood?

2. If a piece of wood has 1/4 as much carbon-14 as compared to a living tree, how old is the wood?

3. It is assumed the relative abundance of carbon-14 in our atmosphere has remained constant for the last 50,000 years. How do you think this assumption could affect carbon dating?

What is Nuclear Fission?

- Nuclear fission is splitting apart a nucleus.
  - Electric force wins against nuclear force
  - Nucleus flies apart releasing huge amounts of energy

- Nuclear fission is used in atomic bombs and nuclear reactors.
  - Atomic bombs produce a chain reaction.
  - Nuclear reactors control the rate of fission.
A little Uranium yields a lot of energy

8.4 x 10^{10} Joules per atom

Practice

Nuclear energy is a clean fuel. It does not pollute the atmosphere. What reasons may people have for not wanting to utilize nuclear energy?

What is Nuclear Fusion?

- Atoms of one type are combined to form atoms of another type.
  - Requires very high temperatures and pressures
  - Nuclei must overcome Coulomb Barrier
  - Some mass is converted into energy

- Fusion occurs naturally in stars.

A Second In The Sun

• $10^{38}$ Reactions
• 600 Billion kg $\rightarrow$ He
• 4 Billion kg Mass $\rightarrow$ Energy
• $4 \times 10^{26}$ Watts

How is radiation measured?

辐射是能量。

- curies：辐射发出
- rad：辐射吸收在介质中
- rem：辐射吸收和可能的生物损伤

辐射量级为$400 – 500$ rems。人体暴露在其中大约为0.2 rems per year。

<table>
<thead>
<tr>
<th></th>
<th>mrems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Food</td>
<td>39 mrems</td>
</tr>
<tr>
<td>Electronics</td>
<td>11 mrems</td>
</tr>
<tr>
<td>Tobacco</td>
<td>1,300 – 9,000 mrems</td>
</tr>
</tbody>
</table>
Smoke Detector

- A weak radioactive source ionizes the air and sets up a small current. If smoke particles enter, the current is reduced, causing an alarm.