Fundamental Forces of the Universe
There are four fundamental forces, or interactions in nature.

- Strong nuclear
- Electromagnetic
- Weak nuclear
- Gravitational

Strongest

Weakest
Strong nuclear force

- Holds the nuclei of atoms together
- Very strong, but only over very, very, very short distances (within the nucleus of the atom)
Electromagnetic force

- Causes electric and magnetic effects
  - Like charges repel each other
  - Opposite charges attract each other
  - Interactions between magnets
- Weaker than the strong nuclear force
- Acts over a much longer distance range than the strong nuclear force
Weak nuclear force

- Responsible for nuclear decay
- Weak and has a very short distance range
Gravitational force

- Weakest of all fundamental forces, but acts over very long distances
- Always attractive
- Acts between any two pieces of matter in the universe
- Very important in explaining the structure of the universe
Remember…

- The weak nuclear force is NOT the weakest of the fundamental forces.
- GRAVITY is the weakest force, but most important in understanding how objects in the universe interact.
Nuclear Reactions

- There are two kinds of nuclear reactions:
  - Fusion
  - Fission

- Protons and neutrons are the two most important subatomic particles in the nucleus and participate in these reactions.
Fusion

- Fusion is the process of combining nuclei of atoms to make different atoms.

- This reaction is going from SMALL to LARGE particles.

- Think of fusing two things together.
Fusion

- Nuclear fusion happens at the sun.
- One atom of hydrogen-3 and one atom of hydrogen combine to form a helium atom, a neutron and lots of energy!!!
Fusion

★ Where does the energy come from?
★ Energy is gained when the two hydrogen atoms break apart.
★ Some of this energy is used up to create the helium atom, but the rest is given off as light.
★ Mass is converted to energy!
   ★ E = mc² (c = 3.0 X 10³⁸ m/s)
   ★ Since the speed of light is so large even a small mass will be converted to a very large energy.
Fission

- Fission is the process of breaking up the nucleus of an atom.
- This reaction is going from LARGE to SMALL particles.
- Think of breaking two things apart.
Fission

- Nuclear fission happens on earth.
- Nuclear fission begins when a neutron hits the nucleus of a large atom.
- Adding this neutron makes the nucleus unstable and it splits into two smaller nuclei and two neutrons.
Fission

235U
If there are other $^{235}$U atoms nearby, the neutrons that came from splitting the first $^{235}$U nucleus can hit other atoms.

The nuclei of these other atoms will release more neutrons and split more $^{235}$U atoms.

This is called a *chain reaction*.
Nuclear Fission
Chain Reaction

- $^{235}\text{U}$
- Neutron
- Fission Product
Radioactivity

- Radioactivity is the process where the nucleus emits particles or energy.

- There are three types of radioactive decay:
  - Alpha decay
  - Beta decay
  - Gamma decay
Alpha decay

- A particle with 2 protons and 2 neutrons is released from an unstable nucleus.

- Alpha decay can be stopped by clothing, skin, a few centimeters of air, or cardboard.
Beta decay

- This occurs when a neutron in the nucleus of a radioactive isotope splits into a proton and an electron.
- The electron is emitted.
- Beta decay can be stopped by dense clothing or wood.
Gamma decay

★ This involves the release of high-energy, electromagnetic radiation from the nucleus of the atom.

★ Gamma rays have even more energy than X-rays.

★ It can only be stopped with thick walls of concrete or lead.
## Radioactive Decay

<table>
<thead>
<tr>
<th></th>
<th>Alpha decay</th>
<th>Beta decay</th>
<th>Gamma decay</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong># of Protons</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong># of Neutrons</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>What is released?</strong></td>
<td>An alpha particle and energy</td>
<td>An electron and energy</td>
<td>A gamma ray (high energy) and energy</td>
</tr>
</tbody>
</table>
## Half-Life

<table>
<thead>
<tr>
<th>Time (years)</th>
<th>Fraction of element left</th>
<th>Amount left (g)</th>
<th>Half-life</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1</td>
<td>80</td>
<td>0</td>
</tr>
<tr>
<td>1000</td>
<td>1/2</td>
<td>40</td>
<td>1</td>
</tr>
<tr>
<td>2000</td>
<td>1/4</td>
<td>20</td>
<td>2</td>
</tr>
<tr>
<td>3000</td>
<td>1/8</td>
<td>10</td>
<td>3</td>
</tr>
</tbody>
</table>
Half-Life

- The half-life of a radioactive element is the **TIME** it takes for **HALF** of the radioactive atoms to decay to stable ones.

- If there are 80 grams of a radioactive element that has a half-life of 1000 years, then after 1000 years half of the element, or 40 grams of the element, will remain.

- Now that there are only 40 grams left, how many grams will be left after another 1000 years has passed?
  - There will be only 20 grams remaining.
The number of half-lives that occur for an element is found by dividing the total time by the half-life of a radioactive element.

Half-life ÷ total time = # of half-lives

An element has a half-life of 1000 years. How many half-lives have occurred after 2000 years has passed?

Two half-lives because 2000 years ÷ 1000 years = 2
Half-Life

- To find the fraction of the original amount think of the original amount as 1 and then divide by 2.
  - \( \frac{1}{2} \), one-half is how much remains after one half-life occurs.

- If two half-lives occur then divide the original amount by 2 twice.
  - \( \frac{1}{(2 \times 2)} = \frac{1}{4} \), one-fourth is how much remains after two half-lives occur.

- What do you do if three half-lives occur?
  - \( \frac{1}{(2 \times 2 \times 2)} = \frac{1}{8} \), one-eighth is how much remains after three half-lives occur.
Half-Life Practice Problem #1

- The radioactive isotope Fluorine-11 has a half-life of 11.0 s. How many half-lives occur in 11.0 s for Fluorine-11?
  - Only one half-life occurs because the half-life of Fluorine-11 is 11.0 s.

- If you started with 30 g, how many grams are left after 11.0 s?
  - Since one half life occurs, 30 g is divided by 2 and there are 15 g left.

- What fraction of the original amount is left?
  - One-half of the original amount is left.
The radioactive isotope Carbon-15 decays very fast and has a half-life of 2.5 s. How many half-lives occur in 5.0 s for Carbon-15?

Two half-lives occur because 5.0 s ÷ 2.5 s = 2.

If you started with 100 g, how many grams are left after 5.0 s?

Since 2 half-lives occur, the 100 g must be divided by 2 twice: 100 g ÷ 4 = 25 g.

What fraction of the original amount is left?

1 ÷ (2×2) = 1 ÷ 4 = 1/4, one-fourth remains.
**Half-Life Practice Problem #3**

- Neon-15 has a half-life of 30 s. How many half-lives occur in 1.5 min?
  - Three half-lives occur because 1.5 min = 90 s and 90 s ÷ 30 s = 3.

- If you started with 56 g, how many grams are left after 1.5 min?
  - Since 3 half-lives occurred, the 39 g must be divided by 2 three times: 56 g ÷ 8 = 7 g.

- What fraction of the original amount is left?
  - $1 ÷ (2 \times 2 \times 2) = 1 ÷ 8 = 1/8$, one-eighth is left.