The Atomic Nucleus & Radioactive Decay

(Chapter 13)

Student Learning Outcome: Analyze radioactive decay and its results, and differentiate between nuclear fission and fusion.

1. *What does radioactivity mean?*
2. *How is radiation measured and when is it dangerous?*
3. *What is the limit for the Strong Nuclear Force?*
4. *What does the half life of an element indicate?*
5. *How do we determine the new isotope?*
6. *What is carbon dating?*
7. *What is Nuclear Fission?*
8. *What is Nuclear Fusion?*

What does radioactivity mean?

- **Radioactivity is the transformation of an unstable atom into a different type of atom, and results in the emission of radiation.**

- Over 60 radioactive elements can be found in nature.

- There are 3 general sources of radioactivity.

    1. Earth
    2. Cosmic Rays
    3. Human Produced

- Some elements are naturally radioactive, emitting energy without absorbing any energy.

How is radiation measured and when is it dangerous?

- **Radiation is energy.**

- The amount of radiation emitted from a material is measured in **Curies**.

- The **rad** is a measurement of the radiant energy absorbed; the joules per kg.

- The **rem** is a unit of the radiant energy absorbed and the possible biological damage that can be caused by different types of radiation.

- Lethal doses begin at about **400 – 500 rems.**

Source	mrems/year
Cosmic Radiation	26 – 50
Earth	16 – 33
Food	39
Atmosphere	198 (depends where you live)
TV and other devices	11
Tobacco (1.5 packs/ day)	1300 – 9000+
Brick house	75
Airline, crew (720 hours) Airline, passenger (10 flights)	160 3
Chest x-ray	5 – 30

- When radiation passes though matter it transfers energy to the electrons.
  - Molecules may be excited or ionized.
  - Cell damage and/or mutation may occur.
  - High radiation doses tend to kill cells.
  - Mutated cells may be passed on to later generations.

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**.
- This strong attractive force holds a nucleus together as long as the diameter of the nucleus does not exceed $\mathbf{10^{-15}\ m}$.
- The strong nuclear force balances the electric force in a stable atom.

Strong Nuclear Force	Electric Force
Attraction	Repulsion
Protons and Neutrons	Protons
Short range	Long range

Question: Would a helium (He) atom or a bismuth (Bi) atom be more stable?

What does the half-life of an element indicate?

- **<u>Half-life</u> is the time it takes for one half of an unstable substance to decay into a different substance.**
  - Shorter half-life = more disintegrations/second
  - Longer half-life = fewer disintegrations/second
- Knowing the half-life and what the element decays into allows dating of matter.

Questions:

1. An isotope of radium (Ra) has a half-life of 1620 years. If 1000 grams were placed in a barrel, how much radium would remain 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 by 1/8?

How do we determine the new isotope?

- Atoms radioactively decay by emitting particles.
- **<u>Alpha radiation</u>** is a positively charged particle (**He^{+}**) ejected at high speed from a decaying nucleus.
  - Alpha particles can cause damage on the surface of a material, the surface of clothing, skin, etc.
- **<u>Beta radiation</u>** is an electron (**e^{-}**) ejected at high speed from a decaying nucleus.
  - Beta particles can penetrate several millimeters of a light material, like living tissue.
- **<u>Gamma</u> <u>Rays</u>** (**γ**) are high energy photons emitted from an excited nucleus.
  - Gamma rays can completely penetrate through many materials, including the human body.

- ❖ When a radioactive nucleus decays, it becomes the nucleus of a new atom.
- ❖ The new element that is formed depends on the radioactive particle emitted.

Unstable Condition	Name	Particle	Charge	Symbol	Rule
83+ Protons	Alpha	$^{2}_{2}He^{+}$	+2	**α**	Mass # − 2 Atomic # − 2
83+ Protons	Heavy Alpha	$^{4}_{2}He^{+}$	+2	**α**	Mass # − 4 Atomic # − 2
Neutron/Proton ratio	Beta	e^{-}	−1	**β**	Mass # − 0 Atomic # + 1
Excited Nucleus	Gamma	**γ**	0	**γ**	No Change

Go To: http://library.thinkquest.org/17940/texts/radioactivity/radioactivity.html

Questions: What is the name of the new isotope, its mass number and its atomic number?

1. $^{226}_{88}Ra \rightarrow X + \beta$
2. $^{226}_{88}Ra \rightarrow X +$ heavy α
3. $^{222}_{86}Rn \rightarrow X + \alpha$
4. $^{14}_{6}C \rightarrow X + \beta$

What is carbon dating?

- ❖ **Carbon dating is the process of using the known half-life of carbon to determine when something died.**
  - ➢ Carbon-14 is continuously produced in the atmosphere and is distributed to living plants and animals in CO_2.
  - ➢ The amount of carbon-14 absorbed is constant during the lifetime of the plant or animal.
  - ➢ At the end of the lifetime, the carbon-14 begins to disintegrate and is not replaced.

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + \beta$$

  - ➢ The amount of carbon-14 remaining in a sample indicates the sample's age.

- **Carbon-14 dating can date materials to about 50,000 years ago**.

- Other radioactive substances are used to date objects that cannot be dated using carbon.

  - Potassium → Argon (rocks and sediments)
  - Uranium → Lead (very old rocks)
  - Rubidium → Strontium (very old terrestrial rocks and lunar samples)

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

1. If a piece of wood is found to have half as much carbon-14 as compared to a living tree, how old is the wood?

2. If the 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?

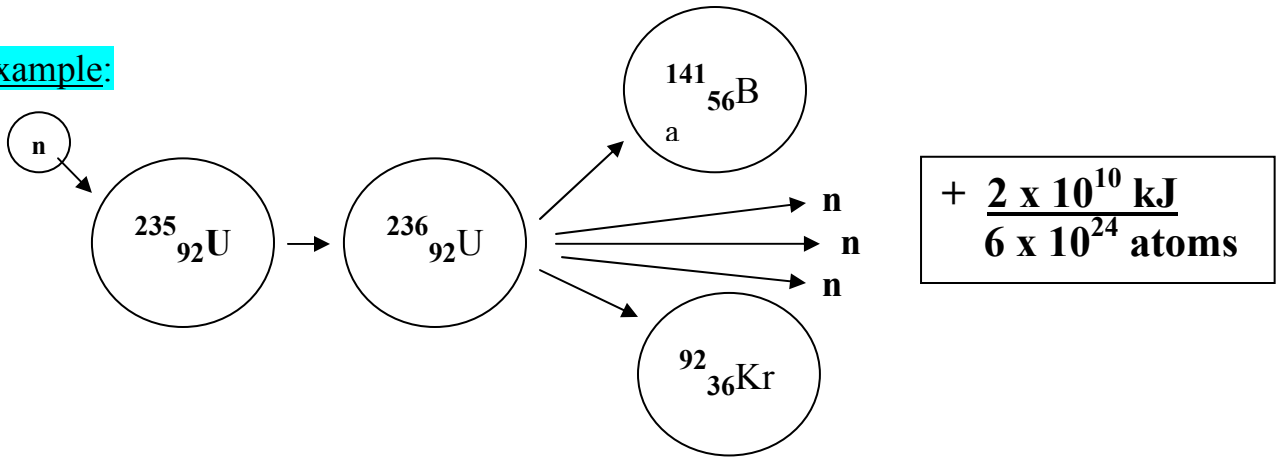
- **Nuclear fission is the splitting apart of a nucleus.**

- Some atoms decay naturally. Some atoms, like uranium, can be made to decay if bombarded with neutrons.

  - Atoms are forced to absorb additional subatomic particles.

  - When the isotope becomes too large, it splits apart quickly.

Example:



- When repulsive electrical forces win against attractive nuclear forces, the nucleus will fly apart.

- Each fission reaction of ^{235}**U** releases 3 neutrons; this results in a rapid **chain reaction**. The number of neutrons released multiplies (3, 9, 27…)

  - **Critical mass** is needed to sustain a chain reaction.

    - Correct mass
    - Correct abundance of U-235

- **Nuclear fission is used in atomic bombs and nuclear reactors**.

- Nuclear reactors control the rate of fission.

- Nuclear energy is considered a clean fuel; it does not pollute the atmosphere.

What is Nuclear Fusion?

- **Atoms of one type are combined to form atoms of another type.**

- Fusion can only occur with very high temperatures and pressures.

  - Nuclei must collide at very speeds to overcome electric repulsion.

- Some mass is converted into energy (**E = mc^2**) when nuclear fusion occurs.

- **Fusion occurs naturally in the cores of stars.**

Example: Proton-Proton Chain (**4H → He + energy**)

Go To: http://csep10.phys.utk.edu/astr162/lect/energy/ppchain.html

The Sun

10^{38} Reactions per Second

600 Billion kg H to He per Second

4 Billion kg Mass → Energy per Second

4 x 10^{26} Watts