Nuclear Decay

Lesson 6

Objectives

- You will be able to write nuclear decay reactions

Nuclear Decay

- **Most atoms are very stable. The strong nuclear force which bonds together the nucleons is stronger than any other force (over very small distances).**
- **It takes a HUGE amount of energy to overcome the strong nuclear force and get out that binding energy.**
- **However in some radioactive elements, atoms are inherently unstable because of size and will decay or release particles and energy, in the process turning into a different element.**
- **The process by which one element decays into another is called transmutation.**

Decay, con't.

- This often occurs when an atom has an abundance of neutrons, swelling the nucleus so that the strong nuclear force is overcome. The larger an atom, the higher the binding energy needed to be overcome.
- The early principles of radioactivity were worked out by Henri Becquerel and Pierre and Marie Curie.

Stability

- You can compare the stability of different nuclei by dividing the binding energy by the number of nucleons in the nucleus.

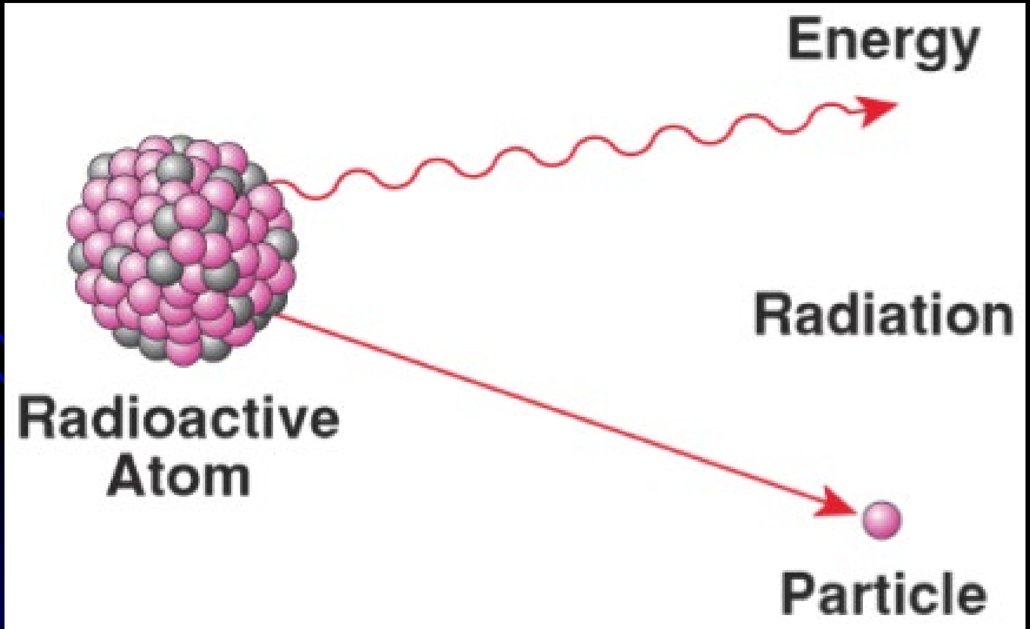
$$Stability = \frac{binding\ energy}{\#\ of\ nucleons}$$

- Order the following atoms from most stable to least stable.

$^{238}_{92}U$ $^{2}_{1}H$ $^{4}_{2}He$ $^{16}_{8}O$ $^{56}_{26}Fe$ $^{3}_{2}He$

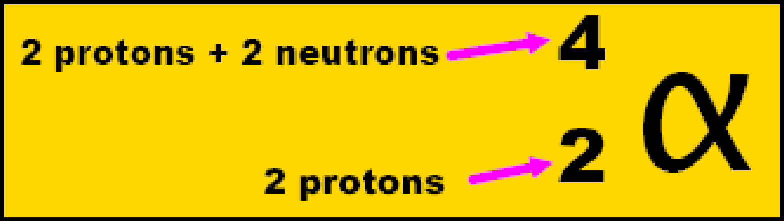
Radioactive Decay

- Unstable radioactive nuclei break apart, but they do not break into halves or large chunks. They only eject small particles.
- This process is called radioactive decay. These ejected particles make up nuclear radiation.



Types of Radiation

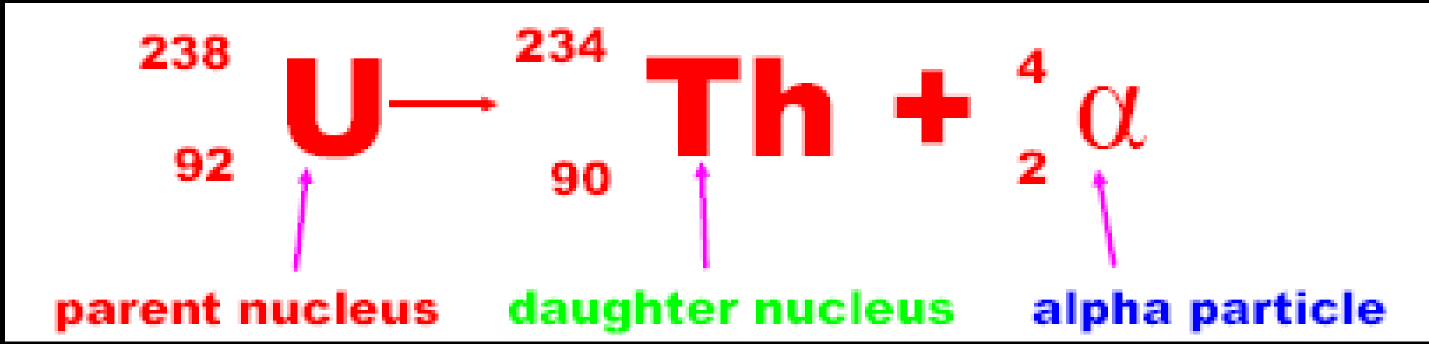
- There are three main types of decay we will study in P30:
- 1. Alpha Decay
- When a radioactive nucleus gives off an alpha particle



- Particles have a charge (+2), a large mass and a short range
- Not suitable for radiation treatment very dangerous if ingested
- Can be stopped by a thick sheet of paper, Al foil or a few cm of air

Alpha Decay

- Ex:



- Complete the decay reactions:

a) $^{222}_{86}Rn \rightarrow ^{x}_{y}Po + ^{4}_{2}\alpha$

b) Write the reaction if plutonium decays alpha

Mass Defect

- We can also calculate mass defects during alpha decay:

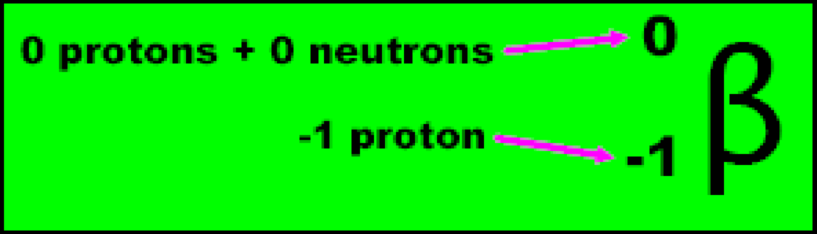
$$\Delta m = m_{parent} - m_{products}$$

- ex) What is the energy released during the alpha decay of uranium-238?

Beta Decay

2. **Beta Decay**

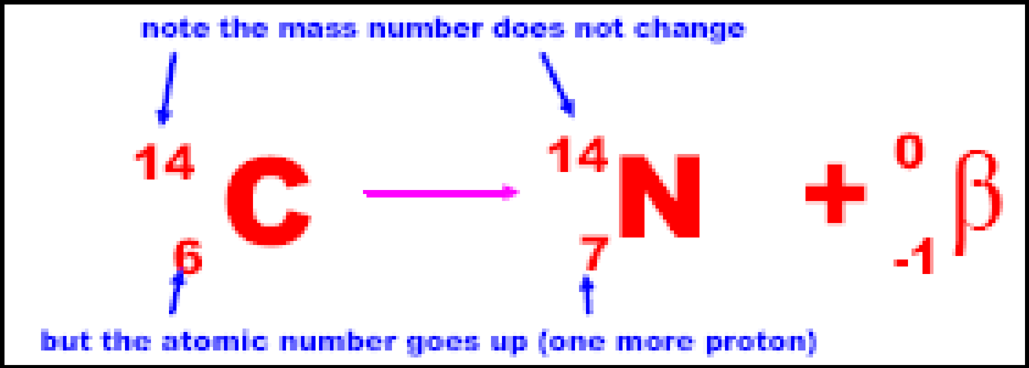
- **When a nucleus gives off a beta particle (electron):**



- **Can still be stopped by a thick piece of paper or a few metres of air**
- **In beta negative decay, a neutron is turned into a proton by the emission of a beta particle and an *antineutrino***

Beta Decay

- ex) carbon-14



The Antineutrino

- ***In order to account for conservation of momentum and energy during decay, we must also introduce another particle, the antineutrino, that has no rest mass and no charge.

$^{0}_{0}\bar{\nu}$ the antineutrino

Full Decay Reaction

- The full beta negative reaction would look like this:

$$ {}^{14}_{6}\mathrm{C} \longrightarrow {}^{14}_{7}\mathrm{N} + {}^{0}_{-1}\beta + {}^{0}_{0}\bar{\nu} $$

- *Note: conservation of mass is obeyed! All protons and
- neutrons are accounted for.
- *Note: conservation of charge is obeyed! A neutron turned
- into a proton and an electron, a net neutral charge.

Examples

- Write the beta-negative decay of:
- a) $^{228}_{88}\mathrm{Ra}$
- b) $^{228}_{82}\mathrm{Pb}$

Mass Defect

- **Note that we can also calculate mass defects with a beta decay as well:**
- **ex) How much energy would be released when $^{228}_{88}Ra$ decays beta-negative?**
- ***note: the mass of the beta particle is so small, it can be ignored.**

$m_{radium\text{-}228}$ = 228.0310703 AMU

$m_{actinium\text{-}228}$ = 228.0310211 AMU

Positive Beta Decay

- A proton can also turn into a neutron through positive beta decay:

$$^{19}_{9}F \longrightarrow {}^{19}_{8}O + {}^{0}_{1}\beta + {}^{0}_{0}v$$

- here, a positive electron (called a positron) is released

- The positron is the antiparticle of the electron also released is the neutrino, v

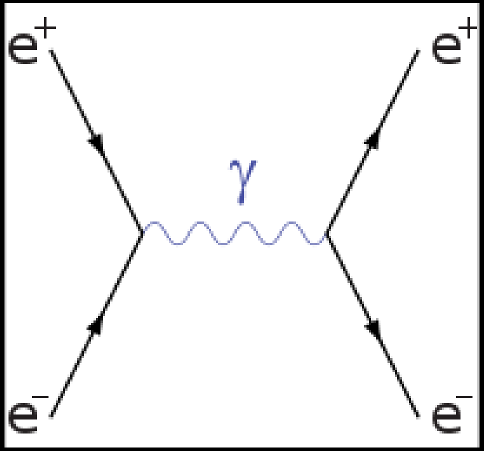
ν and $\bar{\nu}$

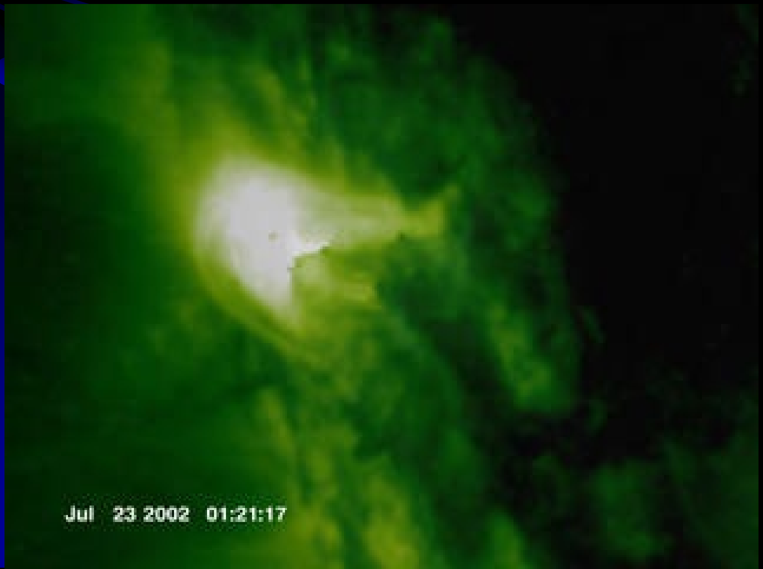
- The neutrino and antineutrino were originally proposed to account for some of the energy and momentum losses in a nuclear reaction. They were later experimentally proven to exist.
- They are identical in every way, except for their spins (a quality of subatomic particles we will study later).

Antimatter Annihilation

- **The antineutrino is a type of antimatter. When matter and antimatter collide, there is a complete annihilation of the matter (actually a pure transfer to energy):**

The annihilation of an electron and positron (beta- and beta+ particle).

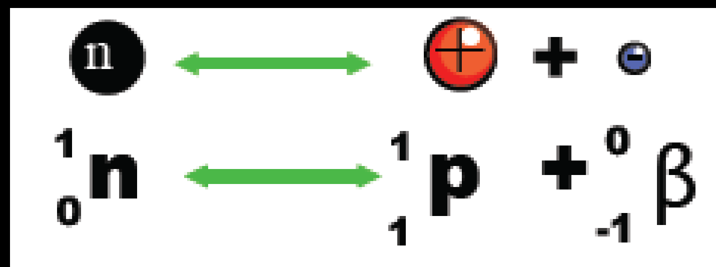




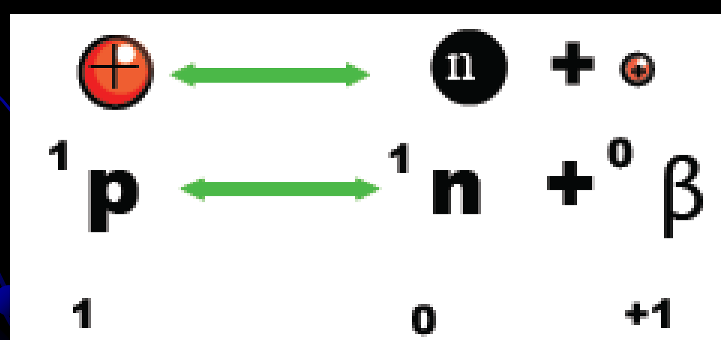
NASA photo of annihilation in a solar flare.

Unique Examples

- **Nuclei having too many neutrons for stability can change a neutron to a proton and an electron (-ive beta decay):**



- **Nuclei having too few neutrons for stability can change a proton to a neutron and a positron (+ive beta decay):**



Gamma Decay

3. Gamma Radiation

- When a gamma ray is emitted, a high energy photon is emitted by the nucleus (i.e. a photon)
- This does not result in transmutation
- These are used in cancer treatment
- Can pass through 30 cm of steel and 1 m of aluminum
- Often occurs with alpha decay

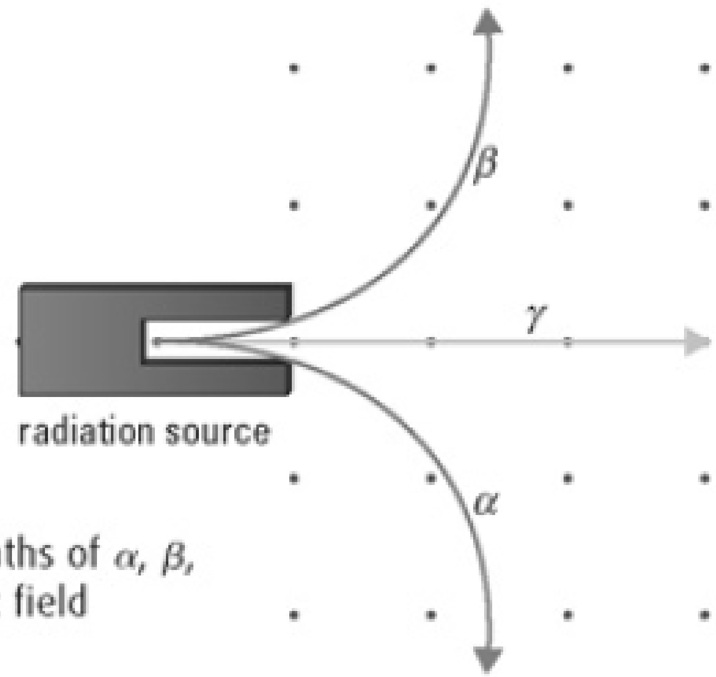
$$^{234}_{90}\mathrm{Th} \rightarrow {}^{230}_{88}\mathrm{Ra} + {}^{4}_{2}\alpha + \gamma$$

gamma ray

Concept Check

Concept Check

Figure 16.5 shows the paths that α, β, and γ rays take when passing through a magnetic field. What can you conclude about the electrical properties of these rays?



▶ **Figure 16.5** The paths of α, β, and γ rays in a magnetic field

Review

- Alpha (α)
  - Large, positively charged particles.
  - Little penetrating power (about one sheet of paper)
- Beta (β)
  - Smaller negatively charged particles.
  - Penetrate as much as three mm of aluminum.
  - Determined to be an electron.
- Gamma (γ)
  - EMR
  - Very high penetrating ability (as much as several cm of lead)

Review

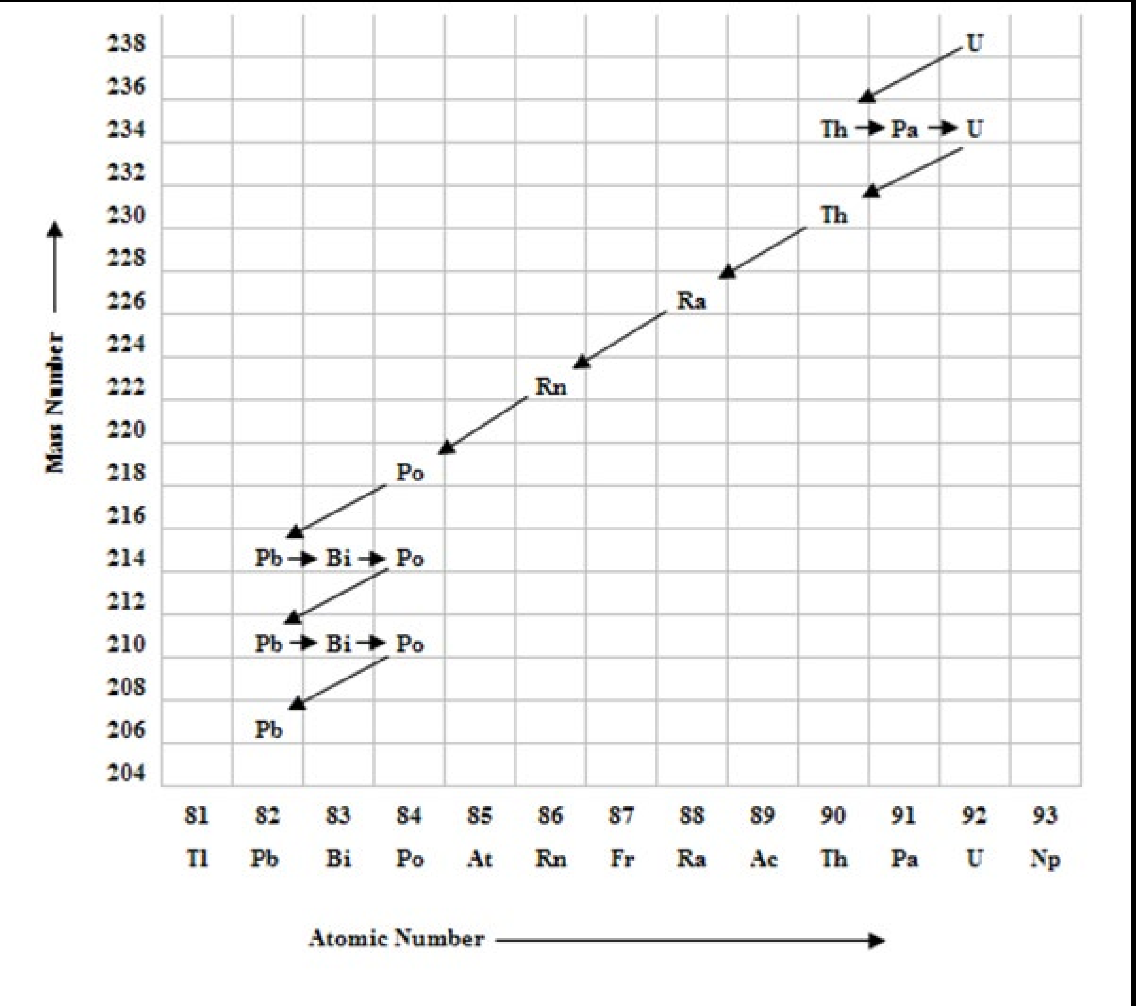
- Alpha Decay
  - The strong nuclear forces in the atom that hold protons and neutrons in the nucleus, are unable to keep some nuclei intact.
  - An alpha particle (helium nucleus) is emitted.
- Beta Decay
  - The weak nuclear force is not always able to hold the quarks together that make up neutrons and protons.
  - When a neutron decays it becomes a proton and an electron (beta particle)
  - The beta particle is ejected from the nucleus, as well as an antiparticle, the electron's antineutrino, leaving a new element that contains one more proton but same mass.
- Positron Emission
  - This is a case of the weak nuclear force being unable to hold the proton together, resulting in the emission of a neutron and a positron, or anti-electron, along with an electron neutrino.

Review

- Gamma Decay
  - A photon emitted when an excited nucleus returns to ground state.
  - Much like an electron can move energy levels so can the protons in the nucleus.
- **Remember: In all decay equations the mass and charge are conserved. (top and bottom numbers)

Decay Series

- When radioactive nuclei decay, they do so in a predictable order called the radioactive decay series. A diagram of the series is shown below:



Decay Series

- This diagram starts with uranium 238 and shows the decay series to the nonradioactive lead 206. Notice the trends:
  - There are downwards decays (where mass number and atomic numbers change)
  - There are sideways decays (where only atomic numbers change)
  - The downward decays indicate alpha decays. An alpha decay involves losing an alpha particle: a change of both mass number and atomic number.
  - The sideways shifts indicate beta decays. The beta decay only involves changing the atomic number, not the mass number.

Biological Effects of Radiation

- The decay process is harmful to living creatures because of the α, β and γ ray's ability to ionize living tissue.
- When molecules in the body are ionized (charged), it throws off delicate body chemistry.
- Large doses of radiation are lethal, small doses which your body encounters naturally can be counteracted by the body with little to no harm.

Extent of Harm

- The extent of harm done depends on the type of radiation:

▼ **Table 16.2** Radiation Hazards from Natural Sources Outside the Body

Radiation	Typical Penetration	Ionization	Hazard
alpha	Travels about 5 cm in air. Cannot penetrate skin.	high	low
beta	Travels about 30–50 cm in air. Penetrates about 1 cm into the body.	moderate	low
gamma	Travels great distances in air. Penetrates right through the body.	low	high

- The amount of time of exposure also plays a role: most radiation sickness is acute, caused by short intense exposure to radiation.
- Chronic exposure, small amounts over long periods of time, is also possible.

Measuring Exposure

- Radiation exposure is measured in at least two ways:
- Gray (Gy): the amount of ionizing energy needed to deliver 1 J of energy to 1 kg of tissue.
- Sievert: (Sv): the amount in Grays, multiplied by the relative biological effectiveness (RBE) factor, different for each type of radiation.

RBE Factors:
α - 20
β - 1
γ - 1

1 Gy of α radiation = 20 Sv
1 Gy of β radiation = 1 Sv
1 Gy of γ radiation = 1 Sv

*A dose of 6 Sv over a short time is fatal.

Examples

1. Write the decay equation for the decay of the neutron, producing beta emission.
2. Write the decay equation for positron decay of carbon-11.
3. Write the decay equation for the alpha decay of radium-226.