Chapter 22 - Nuclear Chemistry

22-1 The Nucleus

I. Introduction
   A. Nucleons
      1. Neutrons and protons
   B. Nuclides
      1. Atoms identified by the number of protons and neutrons in the nucleus
         a. radium-228 or $^{228}_{88}Ra$

II. Mass Defect and Nuclear Stability
   A. Mass Defect
      1. The difference between the mass of an atom and the sum of the masses of its protons, neutrons, and electrons

For $^{4}_{2}He$:

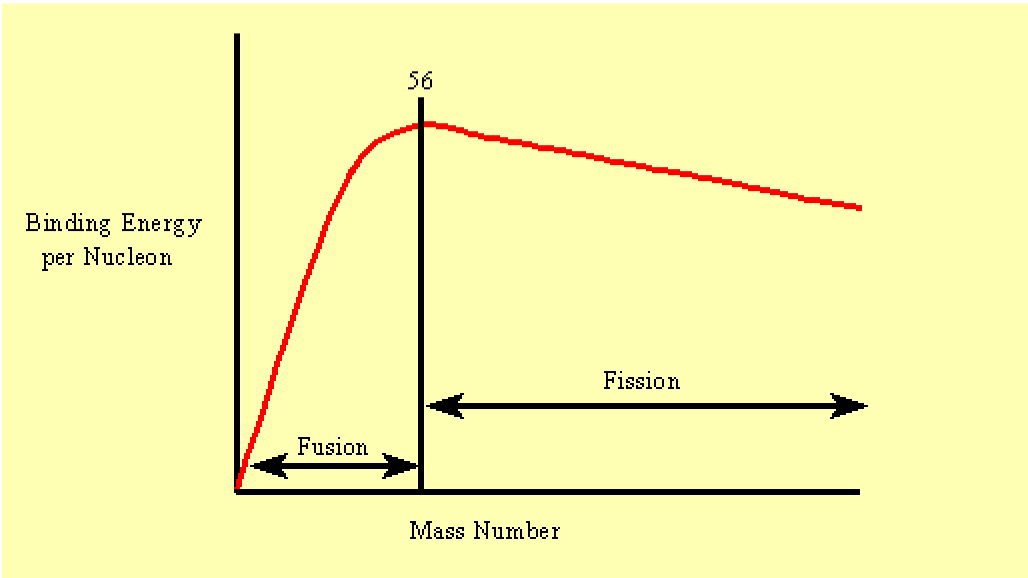
2 protons: (2 x 1.007 276 amu) = 2.014 552 amu
2 neutrons: (2 x 1.008 665 amu) = 2.017 330 amu
2 electrons: (2 x 0.000 5486 amu) = 0.001 097 amu
total combined mass = 4.032 979 amu

Helium's atomic mass = 4.002 60 amu
Mass defect = 0.030 38 amu

   B. Nuclear Binding Energy
      1. The energy released when a nucleus is formed from nucleons
      2. The energy required to break apart the nucleus
      3. Mass defect is related to nuclear binding energy by the equation:

$$E = mc^2$$

   C. Binding Energy per Nucleon
      1. The binding energy of the nucleus divided by the number of nucleons it contains
      2. High binding energy per nucleon results in greater stability



III. Nucleons and Nuclear Stability

A. Band of stability

1. Stable nuclei with favorable neutron-proton ratios

B. Nuclear Shell Model

1. Nucleons exist in different energy levels, or shells, in the nucleus
2. Stable nuclei tend to have even numbers of nucleons
    a. The most stable nuclides have 2, 8, 20, 28, 50, 82 or 126 nucleons
3. The number of neutrons must increase faster than the number of protons in order to overcome proton-proton repulsion
4. No stable nuclides exist beyond atomic # 83, bismuth

IV. Nuclear Reactions

A. Nuclear Reaction

1. A reaction that affects the nucleus of an atom

B. Transmutations

1. A change in the identity of a nucleus as a result of a change in the number of its protons

C. Balancing Nuclear Reactions

1. Total atomic numbers and mass numbers must be equal on both sides

$$ {}^{9}_{4}Be + {}^{4}_{2}He \rightarrow {}^{12}_{6}C + {}^{1}_{0}n $$

22-2 Radioactive Decay

I. Introduction

A. Radioactive Decay

1. The spontaneous disintegration of a nucleus into a slightly lighter and more stable nucleus, accompanied by emission of particles, electromagnetic radiation, or both

B. Nuclear Radiation

1. Particles or electromagnetic radiation emitted from the nucleus during radioactive decay

C. Unstable Nuclides

1. All nuclides beyond atomic # 83 are unstable and radioactive

II. Types of Radioactive Decay

A. Alpha Emission

1. Alpha particle (α) is a helium nucleus (${}^{4}_{2}He$), so it has a 2+ charge.
2. Alpha emission is restricted almost entirely to very heavy nuclei

$$ {}^{210}_{84}Po + \rightarrow {}^{206}_{82}Pb + {}^{4}_{2}He $$

B. Beta Emission

1. Beta particle (β) is an electron emitted from the nucleus during nuclear decay

$$ {}^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}b $$

2. Beta particles are emitted when a neutron is converted into a proton and an electron

$$ {}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}b $$

C. Positron Emission

1. Positrons are particles that have the same mass as an electron, but a positive charge
2. Positron emission arises from the conversion of a proton into a neutron and a positron

$$ {}^{1}_{1}p \rightarrow {}^{1}_{0}n + {}^{0}_{+1}b $$

$$ {}^{38}_{19}K \rightarrow {}^{38}_{18}Ar + {}^{0}_{+1}b $$

D. Electron Capture

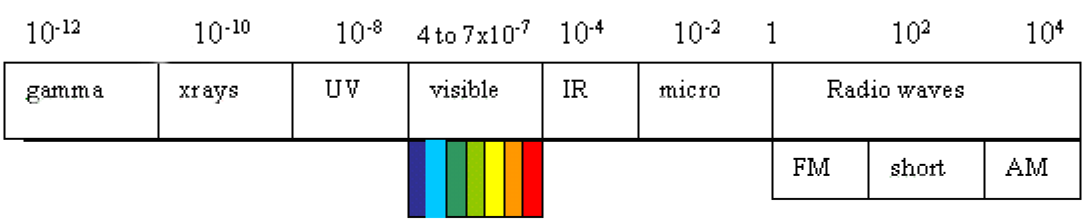
1. Inner orbital electron is captured by the nucleus of its own atom
2. Electron combines with a proton and a neutron is formed

$$ {}^{0}_{-1}e + {}^{1}_{1}p \rightarrow {}^{1}_{0}n $$

$$ {}^{106}_{47}Ag + {}^{0}_{-1}e \rightarrow {}^{106}_{46}Pd $$

E. Gamma Emission

1. Gamma rays () are high-energy electromagnetic waves emitted from a nucleus as it changes from an excited state to a ground energy state
2. Gamma rays are produced when nuclear particles undergo transitions in energy levels
3. Gamma emission usually follows other types of decay that leave the nucleus in an excited state



III. Half-Life

A. Half-Life ($t_{1/2}$)

1. The time required for half the atoms of a radioactive nuclide to decay
    a. More stable nuclides decay slowly
    b. Less stable nuclides decay rapidly

Table 22-2	**Representative Radioactive Nuclides and Their Half Lives**		
Nuclide	*Half-life*	*Nuclide*	*Half-life*
$^{3}_{1}H$	12.32 years	$^{214}_{84}Po$	163.7 μseconds
$^{14}_{6}C$	5715 years	$^{218}_{84}Po$	3.0 minutes
$^{32}_{15}P$	14.28 days	$^{218}_{85}At$	1.6 seconds
$^{40}_{19}K$	1.3 x 109 years	$^{238}_{92}U$	4.46 x 109 years
$^{60}_{27}Co$	10.47 minutes	$^{239}_{94}Pu$	2.41 x 104 years

IV. Decay Series

A. Decay Series
1. A series of radioactive nuclides produced by successive radioactive decay until a stable nuclide is reached

B. Parent Nuclide
1. The heaviest nuclide of each decay series

C. Daughter Nuclides
1. Nuclides produced by the decay of parent nuclides

V. Artificial Transmutations

A. Artificial Transmutations
1. Bombardment of stable nuclei with charged and uncharged particles

B. Accelerators and Cyclotrons
1. Devices used to accelerate particles to speeds/energies required to overcome nuclear repulsion

C. Artificial Radioactive Nuclides
1. "Natural Elements"
    a. Technetium, astatine, francium and promethium
2. Transuranium Elements
    a. All elements beyond #92 are made by transmutation

22-3 Nuclear Radiation

A. Penetrating Ability
   1. Alpha Particles
      a. Least penetrating ability due to large mass and charge
      b. Travel only a few centimeters through air
      c. Cannot penetrate skin
      d. Can cause harm through ingestion or inhalation
   2. Beta Particles
      a. Travel at speeds close to the speed of light
      b. Penetrating ability about 100 times greater than that of alpha particles.
      c. They have a range of a few meters in air.
   3. Gamma rays
      a. Greatest penetrating ability
      b. Protection requires shielding with thick layers of lead, cement, or both

<u>Penetrating ability of radiation</u>

Increasing penetrating ability →

ALPHA ______ BETA ______ GAMMA

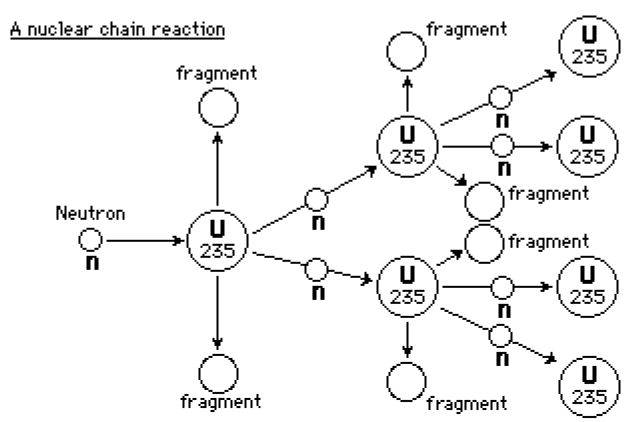
Least harmful ... most harmful

22-4 Nuclear Fission and Nuclear Fusion

I. <u>Nuclear Fission</u>

A. Nuclear Fission
   1. A very heavy nucleus splits into more stable nuclei of intermediate mass
   2. The mass of the products is less than the mass of the reactants. Missing mass is converted to energy

B. Nuclear Chain Reaction
   1. A reaction in which the material that starts the reaction is also one of the products and can start another reaction

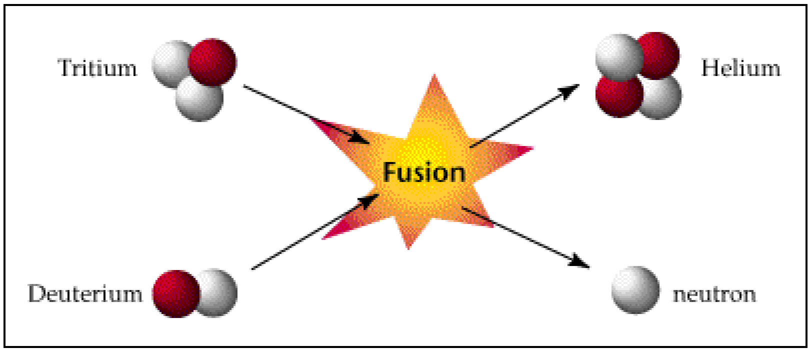


C. Critical Mass
   1. The minimum amount of nuclide that provides the number of neutrons needed to sustain a chain reaction

II. <u>Nuclear Fusion</u>

A. Nuclear Fusion

1. Light-mass nuclei combine to form a heavier, more stable nucleus



B. Fusion Reactions

1. More energetic than fission rxns
2. Source of energy of the hydrogen bomb
3. Could produce energy for human use if a way can be found to contain a fusion rxn (magnetic field?)