Nuclear Chemistry

I. Natural Radioactivity (Transmutation) - spontaneous disintegration of the nucleus of an atom with the emission of particles and/or radiant energy

A. Radioactivity - the nucleus of an atom starts to emit particles

1. element has a large amount of neutrons compared to protons
2. elements above 82 in atomic number (lead)
3. Band of Nuclear Stability – ratio of neutrons to protons must be from 1:1 in smaller atoms to 1.5:1 in larger atoms
    a) As the number of protons in a nucleus increases, the electrostatic force between protons increses faster than the nuclear force. More neutrons are required to increase the nuclear force and stabilize the nucleus
    b) Beyond Bismuth (83) the repulsive force of protons is so great that no stable nuclides exist.

B. Transmutation - when one element is changed to another element because of a change in the <u>nucleus</u>

C. Types of Emanations (particle emissions and radiant energy released) ***See Table O for all symbols used in Nuclear Chemistry***

1. Alpha Decay - alpha particles can be considered Helium nuclei
    a) Atoms which emit alpha particles are called alpha emitters
    b) consist of 2 protons and 2 neutrons
    c) Very little penetrating power
    d) atom affected has atomic # reduced by 2 and atomic mass reduced by 4

Ex. $^{226}_{88}\text{Ra} \rightarrow {}^{4}_{2}\text{He} + {}^{222}_{86}\text{Rn}$

2. Beta Decay - high speed electrons
    a) result of neutron disintegration
        (1) a neutron disintegrates into a proton and electron
        (2) the electron is emitted
    b) atomic number is <u>increased</u> by 1 and the atomic mass <u>remains the same</u>

Ex. $^{234}_{90}\text{Th} \rightarrow {}^{234}_{91}\text{Pa} + {}^{0}_{-1}\text{e}$

3. Gamma Radiation - high energy radiation
    a) not particles
        (1) do not have a mass or charge
    b) reduces the energy content of the nucleus without affecting its charge or mass
    c) Has a very high penetrating power

D. Rules for Natural Radioactive Decay Reactions

1. In natural disintegration of atoms, there is <u>only</u> one atom in the reactants and 2 or more products
2. All numbers on the right must equal the numbers on the left

E. Separating Emanations

1. Magnetic or electric fields
    a) Alpha particles - deflected toward negative pole

b) Beta particles - deflected toward positive pole

c) Gamma rays - not affected

F. Detecting Radioactivity

1. Geiger counter (ionizes other atoms)

2. causes fluorescent and photographic effects

II. Artificial Transmutation (Induced Radioactivity)

A. Artificial Transmutation - the bombarding of elements with high energy particles such as protons, neutrons, and alpha particles to form a new radioactive isotope (radioisotopes)

1. process can be done on smaller atoms

ex. $^{4}_{2}He + ^{14}_{7}N \rightarrow ^{1}_{1}H + ^{17}_{8}O$

(proton)

ex. $^{4}_{2}He + ^{27}_{13}Al \rightarrow ^{1}_{0}n + ^{30}_{15}P$

B. Rules for Artificial Radioactivity Reactions

1. There are at least two reactants on the left side of the equation

2. The sum of the atomic masses and atomic numbers on the left must equal the total number of atomic masses and numbers on the right

C. Particle Accelerators - devices which give charged particles enough kinetic energy to penetrate the nucleus

1. Cyclotron & Synchrotron - uses electromagnets to accelerate particles

2. Linear accelerator - uses fields of electrical force in a linear tunnel to accelerate the particles

III. Nuclear Energy

A. Mass Defect - energy changes due to the changes in binding energy

B. Binding energy - the amount of energy released as nuclear particles merge in the nucleus when some of the mass is converted to energy

Ex. Mass of 2 free neutrons = $1.6748 \times 10^{-24g} \times 2$ = $3.3496 \times 10^{-24}g$

Mass of 2 free protons = $1.6725 \times 10^{-24}g \times 2$ = $\underline{3.3450 \times 10^{-24}g}$

Total mass of 2 free neutrons and protons = $6.6946 \times 10^{-24}g$

Actual mass of He = $\underline{6.641236 \times 10^{-24}g}$

Mass deficiency (binding energy) = $0.053364 \times 10^{-24}g$ ***(Use Einstein's equation to determine the amount of energy released)*** ***Mass is in Kg***

1. Greater binding energy = more stable atom (takes more energy to separate)

C. Fission - the splitting of heavier nuclei into lighter ones (Artificial Transmutation)

1. Only works on unstable elements with high atomic numbers

2. Nucleus captures neutrons causing instability, then splitting into 2 stable elements

a) energy is released (conversion of mass into energy)

b) neutrons are released (can be used to cause further fission reactions -chain reaction)

(1) Atomic bomb - chain reaction is not controlled

(2) Nuclear Reactor - chain reaction is controlled by "control rods"

3. Fission (Nuclear) Reactors

a) Fuels - U 233, U 235, Pu 239 - fissionable materials

(1) Natural Uranium = 99.3% U-238, 0.7% U-235

(2) enriched uranium - has higher U-235 content

(3) Breeder Reactors - use U-238 ® Th-232 and Pu-239 (fuel)

(a) produces more fuel than consumed

b) Moderators - materials that have the ability to slow down neutrons quickly without absorbing them

(1) water, heavy water (with deuterium), beryllium, graphite

c) Control rods - controls number of neutrons available by absorbing them (regulates rate of reaction)

(1) boron, cadmium

d) Coolants - keeps the temperatures from fission at reasonable levels in the reactor

(1) carries heat away to heat exchangers to turn turbines

(2) prevents meltdown in reactor core

(3) water, heavy water, air, helium, carbon dioxide, molten sodium or lithium

e) Shielding

(1) Internal - steel lining to protect walls from radiation damage

(2) External - high density concrete

(a) acts as radiation containment vessel in case of an accident

4. Radioactive Wastes - production of Strontium-90, Cesium-137 must be stored in special containers until they decay

a) Low level radioactive wastes - diluted and released into environment

(1) radon-222, krypton-85, and nitrogen-16 (all decay quickly

5. Fusion Reaction - 2 light nuclei fuse into a heavier nucleus at high temperatures to form a more stable configuration with more binding energy per nucleon (causes release of mass as energy)

a) isotopes produced are stable (not radioactive)

b) Fuels - deuterium and tritium

(1) deuterium - contained in sea water (natural isotope of hydrogen)

(2) tritium - formed by neutron bombardment of lithium

ex. $^{6}_{3}\mathrm{Li} + ^{1}_{0}\mathrm{n} \longrightarrow ^{3}_{1}\mathrm{H} + ^{4}_{2}\mathrm{He}$

c) Problems

(1) High energy requirement - nuclei must have sufficient energy to overcome the charge (repulsion)

(2) Hydrogen must be used because of smallest possible charge

(3) Thermonuclear approach - use high temperatures to cause fusion (10^{9}°C)

(4) Magnetic Bottle approach - use of magnetic fields to confine the reaction

6. Uses of Radioisotopes

a) Tracers in chemical reactions - isotopes act same as stable atom

(1) can be followed in a reaction

ex. C-14, O-18 are used in biology to trace chemical pathways

b) Radioactivity to cure and purify

(1) medical diagnosis, therapy, food preservation

c) Age determination - half-life of various naturally occurring radioisotopes allow scientists to determine the age of artifacts and minerals

IV. Half - Life - the time required for 1/2 of the nuclei of an isotope to disintegrate to a stable form.

A. U 238 ® Pb 206 = 4.5 X 10^{9} years (series of alpha and beta emissions)

B. C 14 ® N 14 = 5700 years (beta decay)

    1. effective up to 40,000 years old

C. ***See Table N in the reference tables for other radioisotopes***