Notes: Nuclear Chemistry

• **NUCLEAR REACTIONS**: involve changes in the composition on nuclei Accom by the release of huge amounts of energy

• **NUCLEAR FISSION**: The splitting of a heavy nucleus into lighter nuclei

• **NUCLEAR FUSION**: The combination of light nuclei to produce a heavy nucleus

• **NUCLIDES**: Different atomic forms of all elements

-most nuclides have even # of protons and neutrons

some nuclides have "magic #s" of protons and neutrons and are especially stable

• ***The neutron-to-proton ratio determines the stability of the nucleus:***

-for low atomic #'s: Equal #s of protons & neutrons

-above atomic #20: More neutrons than protons

• nuclei whose neutron-to-proton ratio is unstable undergo radioactive decay by emitting 1 or more particles and/or electromagnetic rays:

Type	Symbol	Identity	Mass (amu)	Charge	Penetration
Alpha $^4_2\alpha$ or ^4_2He	$^4_2\alpha$ or ^4_2He	helium nucleus	4.0026	2+	low
Beta	$^0_{-1}\beta$ or $^0_{-1}e$	electron	0.00055	1-	low-med
Gamma	$^0_0\gamma$	high energy radiation	0	0	high
Proton	^1_1p or ^1_1H	proton H nucleus	1.0073	1+	low-med
Neutron	^1_0n	neutron	1.0087	0	very high

NUCLEAR EQUATIONS:

Example 1: Radon-226 transmutates by alpha decay. Write the nuclear equation that represents this process:

$$^{226}_{88}Ra \rightarrow ^{4}_{2}\alpha + ^{222}_{86}Rn$$

Example 2: Write the nuclear equation for the beta-decay of boron-12.

$$^{12}_{5}B \rightarrow ^{0}_{-1}\beta + ^{12}_{6}C$$

Example 3: Write the nuclear equation representing gamma radiation given off by the unstable radionuclide cobalt-~~226~~.

cobalt-60

$$^{60}_{27}Co \rightarrow ^{60}_{27}Co + \gamma$$

Nuclear Fission & Fusion

• FISSION: a heavy nucleus splits into 2 lighter nuclei

*some elements fission spontaneously

* some elements can be induced to undergo fission when bombarded with other particles (e.g. neutrons)

• FUSION: 2 nuclei combine to form a heavier nucleus

*the sun is a tremendous fusion reaction; the major fusion reaction in the sun is thought to be:

$^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + ^{1}_{0}n$ + energy

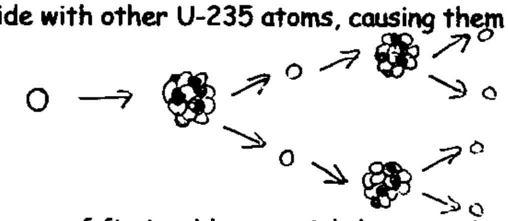
*both fission & fusion release large amounts of energy (fusion more than fission)

• The Atomic Bomb (FISSION)

-when the nucleus of U-235 splits, 2 isotopes are formed, plus neutrons are emitted

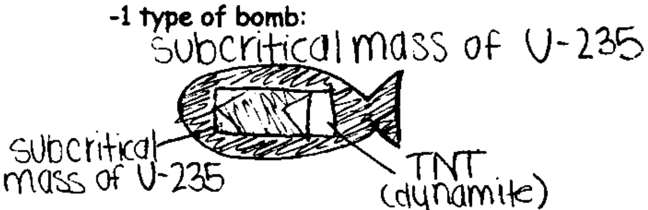
-these neutrons collide with other U-235 atoms, causing them to undergo fission; they release neutrons, and so on...

The Result... CHAIN REACTION!!



-there is a minimum mass of fissionable material that must be used to sustain a chain reaction: **CRITICAL MASS!**

-1 type of bomb:



• Nuclear Reactors (FISSION)

*use subcritical masses of fissionable material

• CORE: contains fuel pins made of U-235; interspersed among the pins are control rods

*control rods: absorb neutrons

*pull rods out of core: fission increases

*push rods back into the core: fission decreases

***Safety feature**: *if power is lost, rods will automatically fall into the core and shut the reaction down.*

TO GENERATE ELECTRICITY:

1) Fission heats up water in vessel and heat is carried away
2) This heat is used to heat up water in a second system, which turns to steam
3) Steam turns turbine of a generator
4) Generator makes electricity

PROS OF NUCLEAR ENERGY:

- no air pollution
- enormous amt. of energy released.
- alternative to using limited fossil fuels

CONS OF NUCLEAR ENERGY:

- containers for waste products may crack or break
- thermal pollution (heated water returned to rivers)
- Potential theft of fuel for weapons

Notes – Rates of Decay and Half-Life

Radionuclides have different stabilities and decay at different rates.

Integrated rate equation:

$$\log\left(\frac{A_o}{A}\right) = \frac{Kt}{2.303}$$

where...

A = the amt. of decaying sample remaining at some time, t
A_o= the amt. of sample present at the beginning
K = rate constant; different for each radionuclide
t = time

--- OR ---

$$\log\left(\frac{N_o}{N}\right) = \frac{Kt}{2.303}$$

N = # of disintegrations per unit of time; relative activity
N_o= original activity

Half-life = the amount of time required for half of the original sample to decay

$$t_{1/2} = \frac{\ln 2}{K} = \frac{0.693}{K} \qquad K = \frac{0.693}{t_{1/2}}$$

Example: Cobalt-60 decays with the emission of beta particles and gamma rays, with a half-life of 5.27 $= t_{1/2}$ years. How much of a 3.42 μg of cobalt-60 remains after 30.0 years?

A_o $A = ?$ t

$$K = \frac{0.693}{5.27\ \text{years}} = 0.1315\ yr^{-1}$$

$$\log\left(\frac{A_o}{A}\right) = \frac{Kt}{2.303}$$

$$\log\left(\frac{3.42}{A}\right) = \frac{0.1315\ yr^{-1}(30)}{2.303} = 1.713$$

$$\log\left(\frac{3.42}{A}\right) = 1.713$$

$$\left(\frac{3.42\ \mu g}{A}\right) = 10^{1.713}$$

$$3.42\ \mu g = 51.6 \times A$$

$$A = \frac{3.42\ \mu g}{51.6} \qquad \boxed{A = 0.0662\ \mu g}$$

Uses of Radionuclides

Radiocarbon dating: the ages of specimens of organic origin can be estimated by measuring the amount of cabon-14 in a sample.

Example: A piece of wood taken from a cave dwelling in New Mexico is found to have a carbon-14 activity (per gram of carbon) only 0.636 times that of wood today. Estimate the age of the wood. (The half-life of carbon-14 is 5730 years.)

$$K = \frac{0.693}{5730\ yrs} = 0.00012094\ yr^{-1}$$

$$\log\left(\frac{N_o}{N}\right) = \frac{Kt}{2.303} \qquad N = 0.636\ N_o$$

$$\log\left(\frac{N_o}{0.636 N_o}\right) = \frac{(0.00012094\ yr^{-1})(t)}{2.303}$$

$$\log\left(\frac{1}{0.636}\right) = (5.25 \times 10^{-5}\ yr^{-1})(t)$$

$$t = 3743.67 \approx 3744 \approx \boxed{3740\ years}$$

***<u>NOTE</u>: Objects older than 50,000 years have too little activity to be dated accurately using carbon dating; instead the following methods are used:

1. Potassium-40 decays to argon-40: half-life = 1.3×10^9 years
2. Uranium-238 decays to lead-206: half-life = 4.51×10^9 years

Example: A sample of uranium ore is found to contain 4.64 mg of uranium-238 and 1.22 mg of lead-206. Estimate the age of the ore.

$$1.22\ mg\ Pb \times \frac{238\ g/mol\ U}{206\ g/mol\ Pb} = 1.41\ mg\ U\text{-}238 \text{ have decayed}$$

$$A_o = 1.41 + 4.64\ mg = 6.05\ mg\ U$$

$$K = \frac{0.693}{4.51 \times 10^9\ yrs} = 1.536585366 \times 10^{-10}$$

$$\log\left(\frac{A_o}{A}\right) = \frac{Kt}{2.303}$$

$$\log\left(\frac{6.05\ mg}{4.64\ mg}\right) = \frac{(1.54 \times 10^{-10}\ yr^{-1})(t)}{2.303}$$

$$t = 1.73 \text{ billion years}$$