Nuclear Chemistry – Lecture Notes:

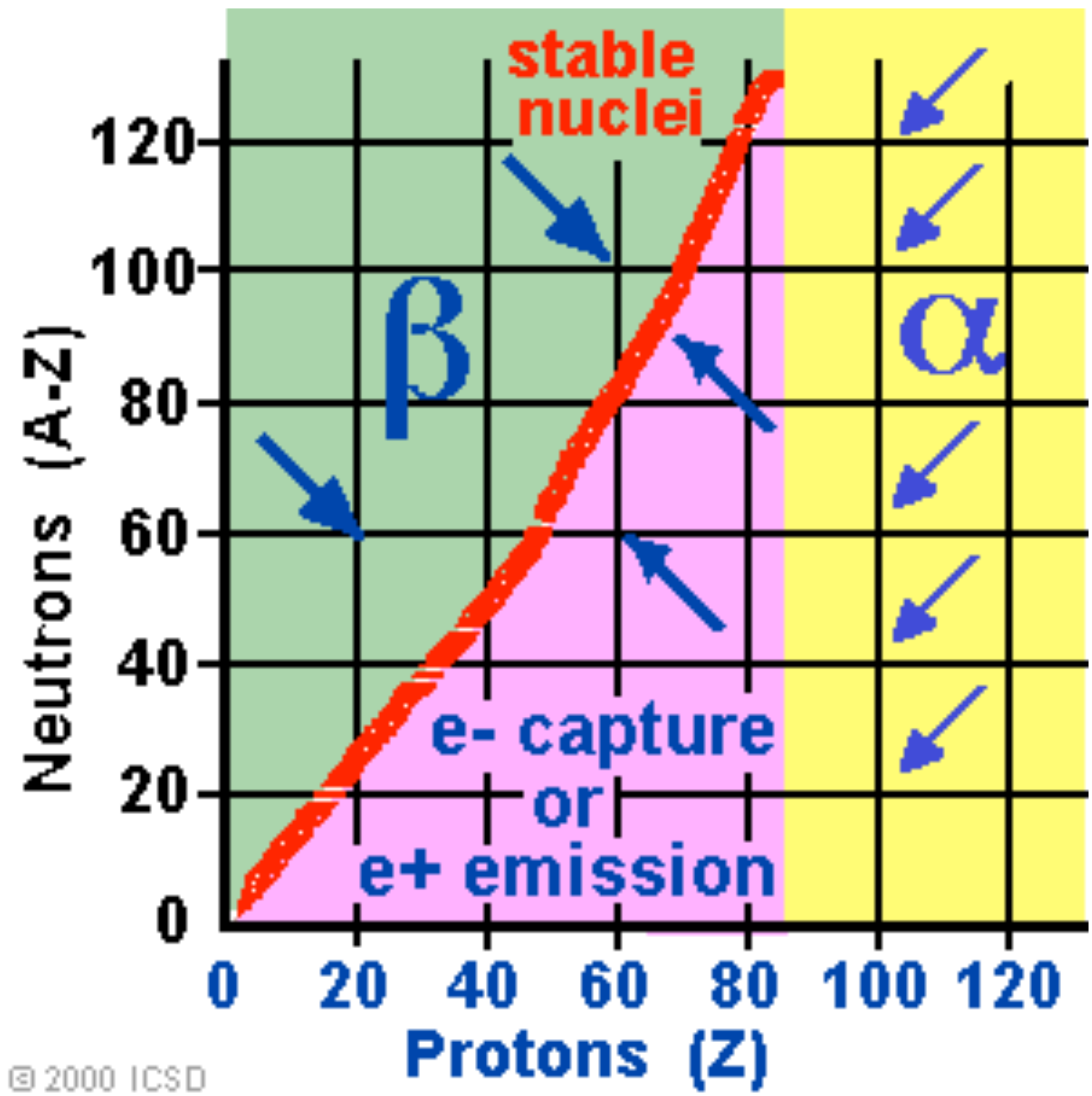
I Radioactive Decay

A. Type of decay: See table

Type	Symbol	Charge	Mass (AMU)	Effect on Atomic #	Effect on Atomic Mass	Strength
Alpha	**α**	**+2**	**4**	**decrease by 2**	**decrease by 4**	**Stopped by paper**
Beta	**β- electron**	**-1**	**0**	**increase by 1**	**0**	**Aluminum Foil**
Beta	**β+ Positron decay**	**+1**	**0**	**decrease by 1**	**0**	**Aluminum Foil**
Gamma	**γ**	**none**	**none**	**none**	**none**	**Lead**

B. Predicting Atomic Stability

How can two positively charged protons sit side by side? Answer: the *strong nuclear force*, exists between nucleons. All nuclei with two or more protons contain neutrons. The more protons packed in the nucleus, the more neutrons are needed to bind the nucleus together. Stable nuclei with low atomic numbers (up to about 20) have approximately equal numbers of neutrons and protons. However, as the atomic number increases, the number of neutrons increases faster.



Predicting type of decay:

The type of radioactive decay that a particular radionuclide undergoes depends to a large extent on its neutron-to-proton ratio compared to those of nearby nuclei within the belt of stability. We can envision three general situations:

1. *Nuclei above the belt of stability (high neutron-to-proton ratios) undergo Beta Decay (neutron→ proton)*

2. *Nuclei below the belt of stability (low neutron-to-proton ratios) Undergo Positron decay (also known as electron capture)*
proton → neutron

3. *Nuclei with atomic numbers 84:* Emit an alpha particle decreasing both the number of neutrons and the number of protons by 2, moving the nucleus diagonally toward the belt of stability.

Magic Numbers:

• Nuclei with 2, 8, 20, 28, 50, or 82 protons or 2, 8, 20, 28, 50, 82, or 126 neutrons are generally more stable. These numbers of protons and neutrons are called **magic numbers**.

• Nuclei with even numbers of both protons and neutrons are generally more stable than those with odd numbers of nucleons.

Number of Stable Isotopes	Protons	Neutrons
157	Even	Even
53	Even	Odd
50	Odd	Even
5	Odd	Odd

C. Nuclear Transformation of elements

By bombarding atomic nuclei with protons, it is possible to create new elements:

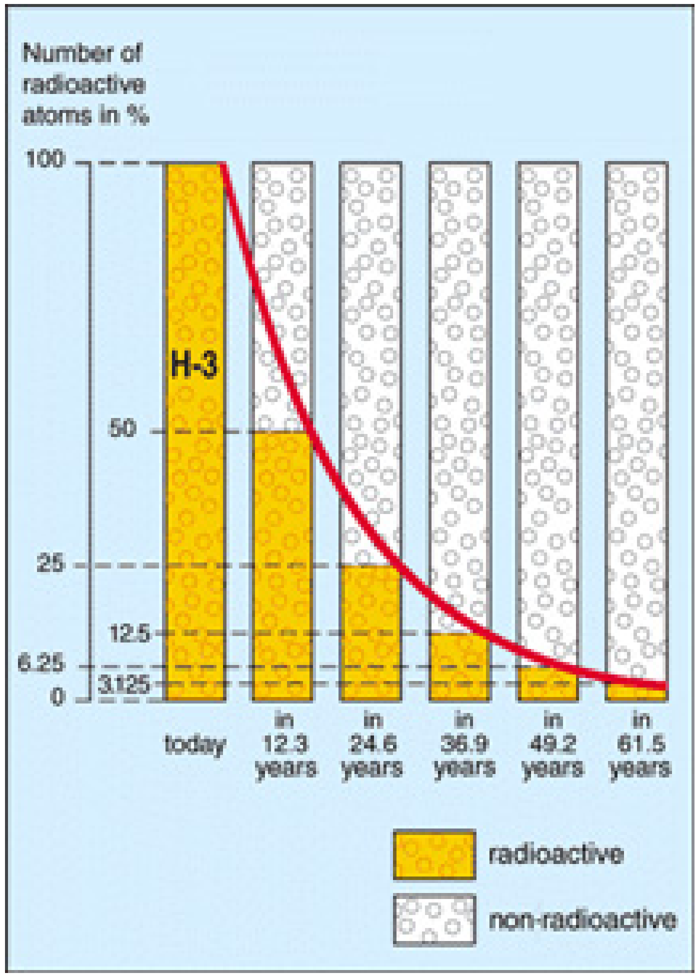
$$^{14}_{7}N + ^{4}_{2}He \rightarrow ^{17}_{8}O + ^{1}_{1}H$$

This reaction demonstrated that nuclear reactions can be induced by striking nuclei with particles such as alpha particles.

II: Radioactive decay/ Half lives

Some nucleus are unstable and break down. Process is random for any single nucleus but predictable for large number.

Half life = period of time needed for half the atoms in a sample to decay.



Varies by isotope Te-128 = 1.5 x 10^{24} years; Ra-216 = 7 x 10^{-7} s

$$\frac{m_i}{2^n} = m_f \qquad T = (t_{1/2})(n)$$

(n=# of half-lives)

Example: How long would it take for a sample of Rn-222 that weighs 0.750 g to decay to 0.100 g? Assume a half-life for Rn-222 of 3.823 days

$$\frac{.750g}{2^n} = .100g \quad 2^n = \frac{.750}{.100} = 7.5 \quad n \ln 2 = \ln(7.5) = \frac{\ln(7.5)}{\ln 2}$$

n= 2.907 so t= (2.907 x 3.823 days) = 11.1 days

C-14 has a half life of 5730 years. An artifact has 32.0% of its original C-14. How old is it?

$$2^{-n} = 0.320 \qquad -n(\ln 2) = \ln(0.320) \quad n = 1.644 \quad \text{half lifes}$$

object age = 1.644 x 5730 years = 9420 years old

III. Balancing Nuclear Equations: Matter must be conserved including all p+ & n°. Example:

$$^{219}_{86}\text{Rn} \longrightarrow {}^{4}_{2}\text{He} + {}^{215}_{84}\text{Po}$$

IV. Energy – Matter conversion

A. $E = mc^2$.

E = joules; m = Kg; c = 3 x 10^8 m/s note: 1J = 1kg m^2/s^2

Example: Convert 1 kg of matter to energy:

E = 1kg x (3 x 10^8m/s)^2 = 9 x 10^{16} J = 9.0 x 10^{13} kJ

How much energy is this?

Mass of Ocean = 1.4 x 10^{11} kg. = 7.8 x 10^{12} moles of water. Heat of vaporization of water = 6.0 kJ/mol there is more than enough energy to boil off the oceans!

B. Mass defects: The difference between the predicted mass of the atom and the actual. Two types:

1. Fission: (splitting atoms) **1 amu = 1.661 x 10^{-27} kg**

$$^{238}U \rightarrow {}^{234}Th + {}^{4}He + \text{Energy}$$

	Atomic Mass (amu)
^{238}U	238.0508
^{234}Th	-234.0436
^{4}He	- 4.0026
Difference (Mass defect)	0.0046 Amu

$E = mc^2 = .0046 \times 1.661 \times 10^{-27} \times 9.00 \times 10^{16} = 6.88\times10^{-12}$ J

How much energy per gram of U-238? (1.74 x 10^{10} J)

Chain Reaction: Atomic Decay initiated by neutron capture results in production of two or more neutrons which initiate new decays resulting in a geometric increase with each new cycle. For example:

$$^{1}_{0}n + {}^{235}_{92}U \longrightarrow {}^{92}_{36}Kr + {}^{141}_{56}Ba + 3\ {}^{1}_{0}n$$

A controlled nuclear chain reaction is used in power plants, an uncontrolled nuclear reaction is used in a bomb. The reaction can be controlled by using materials that absorb neutrons and prevent the reaction from going critical.

2. Fusion: (combining atoms)
   In stars, 4 hydrogen are converted to 1 helium:

4 Hydrogen	=	6.693×10^{-27} kg
1 Helium	=	6.654×10^{-27} kg
Difference	=	0.048×10^{-27} kg

How much energy is produced? 4.32×10^{-12}J not very much? 1g of Hydrogen converted to He = 6.50×10^{11}J (each person in the U.S. uses about 3.9×10^{11} J per year)