Nuclear Chemistry

Radioactivity -- the tendency of an unstable nucleus to emit radiation

What makes a nucleus stable?
1) Atomic number less than or equal to 83
2) Ratio of neutrons to protons = 1 for light elements (atomic number <20)
3) Ratio of neutrons to protons less than or equal to 1.6 for heavier elements
4) an even number of both of protons and neutrons
5) a "magic" number of protons or neutrons – 2, 8, 20, 28, 50, 82, and 126

Nuclear Decay Processes

1) Alpha (α) decay – emission of an α particle, which is simply a He nucleus, ${}^{4}_{2}He$

${}^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}He$ α decay is a way for a heavy unstable nucleus to decrease its mass

!!!! **Note** that protons and neutrons (and mass number) are balanced in the nuclear equation !!!!

2) Beta (β) decay – emission of a β particle, which is simply an electron, ${}^{0}_{-1}e$ or ${}^{0}_{-1}\beta$

$${}^{3}_{1}H \longrightarrow {}^{3}_{2}He + {}^{0}_{-1}e$$

** In β decay, a neutron is transformed into a proton and β particle: ${}^{1}_{0}n \longrightarrow {}^{1}_{1}p + {}^{0}_{-1}e$

Because β decay destroys a neutron and makes a proton, it tends to occur when the ratio N/Z is too large

3) Positron decay – the opposite of β decay $\longrightarrow$ emission of a positron ${}^{0}_{1}\beta$

$${}^{30}_{15}P \longrightarrow {}^{30}_{14}Si + {}^{0}_{1}\beta$$

** In positron decay, a proton is transformed into a neutron and a positron ${}^{1}_{1}p \longrightarrow {}^{1}_{0}n + {}^{0}_{1}\beta$

Positron decay will tend to occur when the ratio N/Z is too small

4) Gamma (γ) ray emission – emission of high-energy radiation, which always occurs in conjunction with alpha or beta decay

5) Electron Capture – the nucleus captures a core electron, destroys a proton, and emits a gamma ray

$${}^{201}_{80}Hg + {}^{0}_{-1}e \longrightarrow {}^{201}_{79}Au + {}^{0}_{0}\gamma$$

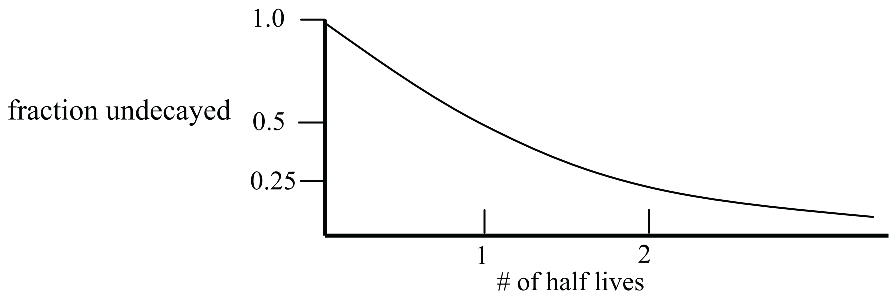
Nuclear Bombardment Reactions (Nonspontaneous Transmutation)

$${}^{14}_{7}N + {}^{4}_{2}\alpha \longrightarrow {}^{17}_{8}O + {}^{1}_{1}p \quad \text{(Rutherford, 1919)}$$

*** Bombardment reactions are used to synthesize the transuranium and other non-natural elements ****

<u>Half-life</u> ($t_{1/2}$) – the time required for one-half of the radioactive atoms in a sample to decay

Half-life equation ⟶ Fraction remaining = $\left(\frac{1}{2}\right)^n$ where n is the number of half-lives gone by



***** **Note: All nuclear decay processes occur by first-order kinetics** *****

Classic Use of Nuclear Decay **radioactive dating (e.g. carbon-14 dating)**

Example 1 – A bottle of wine was found to contain 2% of the tritium (^3H) that was originally present when the wine was bottled. If the half-life of tritium is 12.3 yr, how old is the bottle of wine?

A typical step in half-life problems is to express amount in terms of only the initial amount.
It is a first order decay process and you should know the integrated form of a first order rate law and the relationship between the half-life and the rate constant.

$$\ln[A] - \ln[A]_o = -kt \qquad t_{1/2} = \frac{.69}{k} \longrightarrow k = .69/12.3 \text{ yrs} = .056 \text{ yrs}^{-1}$$

$$\ln\left(\frac{.02\,A_o}{A_o}\right) = -(.056 \text{ yrs}^{-1})t \longrightarrow t = 70 \text{ yrs}$$

Energetics of Nuclear Transformations (Binding Energy, etc.)

Nuclear binding energy is the energy required to break up a nucleus into its component protons and neutrons. This is the conversion of mass to energy that accompanies an exothermic nuclear reaction.

<u>Essential info</u>: m_{proton} = 1.0078 amu; $m_{neutron}$ = 1.0087 amu; 1 amu = 1.66×10^{-27} kg

The difference between the mass of an atom and the sum of the masses of its protons, neutrons and electrons is called the **mass defect.**

In both cases you can calculate the amount of energy associated with a mass difference using Einstein's relation

$$\Delta E = (\Delta m)c^2$$

ΔE = the energy released
Δm = the mass difference between the nucleus and the sum of the individual components
c = the speed of light 2.998×10^8 m/s

Make sure that your units are consistent. Use **joules** for energy, **kilograms** for mass and **meters/second** for speed