PAM1014
Introduction to Radiation Physics

"Radioactive Decay"

Objectives

- Nuclides
- Radioactivity
- Radioactive Decay Process
- Half-Life
- Decay Constant

Nuclides

A = Mass Number
Z = Atomic Number
N = Number of Neutrons

$$^{A}_{Z}X_{N}$$

- Species of atoms characterised by:
  - Number of protons
  - Number of neutrons
  - Energy content of the atomic nucleus
    - Two forces acting in opposition:
      - Repulsive Coulomb force between protons
      - Attractive force of subnuclear particles

Nuclear Stability

- Only certain combinations of neutrons and protons in nucleus are stable.
- Line of stability
  - $N/Z \approx 1$ for low Z nuclides
  - $N/Z \approx 1.5$ for high Z nuclides
- Nuclides with odd number N and Z tend to be unstable!

Radioactivity

- Unstable combinations of N and Z exist
  - BUT overtime permute to stable nuclei
- Stability achieved by conversion of a N to Z or *vice versa*
  - Accompanied by emission of energy

Radioactive Decay

- Nuclides that decay to a more stable nuclei
  - Radioactive
  - Several Types
- A nuclide may undergo several decays before it becomes stable
  - Decay chain
  - Example: Uranium 238 has 14 successive decays to form a stable Lead 206

Radioactive Decay

- Parent Nuclide:
  - Radionuclide at the beginning of a particular decay
- Daughter Nuclide:
  - Nuclide produced by decay
  - May or may not be stable

Nuclear Transformation

- Most radionuclides decay in one or more of the following ways:
  - Alpha decay (α)
  - Beta-minus emission (β-)
  - Beta-plus (positron) emission (β+)
  - Electron capture
  - Isometric transition

Alpha Decay

- The spontaneous emission of an alpha particle from nucleus
  - Identical to a helium nucleus consisting of 2 protons and 2 neutrons.
- Seen in heavy nuclides (A>150)
- Often followed by gamma and characteristic x-ray emission.

Alpha Particle

- The heaviest and least penetrating form of radiation
- Emitted from atomic nucleus with discrete energies in range 2 – 10 MeV
- Approximately FOUR times heavier than a proton or neutron.

Alpha Decay

- Described by the following equation

$$ {}^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He^{2+} + \text{transition energy} $$

- Alpha particles not typically used in medical imaging
  - Limited range (1 cm / MeV in air and less than 100 μm in tissue)

Beta-Minus (Negatron) Decay

- Radionuclides with excess of neutrons
  - High N/Z ratio
- Described by the following equation:

$$ {}^{A}_{Z}X \rightarrow {}_{Z+1}^{A}Y + \beta^{-} + \overline{\nu} + \text{energy} $$

Beta-Minus (Negatron) Decay

- Decay results in conversion of a neutron into a proton
- Simultaneously ejects
  - a negatively charged beta particle (negatron)
  - An antineutrino
- Increases number of protons by 1 thus turns atom into different element of atomic number Z+1

Beta-Minus (Negatron) Decay

- Beta particle identical to ordinary electron
- Antineutrinos have infinitesimal mass and no charge, so hard to detect
- Beta-minus decay decreases N/Z ratio, therefore the daughter closer to stability

Beta-Plus Decay (Positron Emission)

- Same as beta-minus, driven by nuclear instability
  - This time due to deficiency of neutrons
- Increases the neutron number by 1
- Described by the following equation:

$$ {}_{Z}^{A}X \rightarrow {}_{Z-1}^{A}Y + \beta^{+} + \nu + \text{energy} $$

Beta-Plus Decay (Positron Emission)

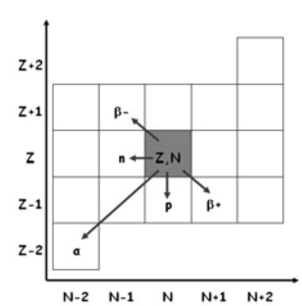
- Decay results in conversion of a proton into a neutron
- Simultaneously ejects
  - a positively charged beta particle (Positron)
  - A neutrino
- Decreases number of protons by 1 thus turns atom into different element of atomic number Z-1

Beta-Plus Decay (Positron Emission)

- Increases number of neutrons by 1
- Positron decay increases N/Z ratio
- Medical uses:
  - Positron-emitting radiopharmaceuticals
  - Positron emission tomography (PET)

Radioactive Decay Process

- Useful for visualising
- Parent nuclide decays to one or more daughter nuclide.



Decay Constant

- Radioactive decay is a random process
- Impossible to predict which radioactive atoms in a sample will decay given a moment in time
- Observation of large number of radioactive material, over a period of time allows average rate of decay

Radioactivity

- Rate of Decay
- Measured in becquerel (bq)
- 1 bq = 1 decay per second
- 1 bequerel = amount of material which will produce 1 nuclear decay per second.

Decay Constant

- The relationship between activity (A) and Decay Constant (λ) is

$$A = \lambda N$$

- Where N = number of unstable atoms
- Decay constant is characteristic of each radionuclide

Decay Constant

- SI units of Decay Constant (λ)
  - Unit of s^{-1},
  - $Hour^{-1}$ or $year^{-1}$ also used
- The Decay Constant is an indicator of how fast OR slow a material will decay
  - Large λ = sample decays quickly
  - Small λ = sample decays slowly

Physical Half-Life

- Parameter related to decay constant is the Physical Half-Life ($T_{1/2}$)
- Definition: Time required for the number of radioactive atoms in a sample to decrease by ONE half

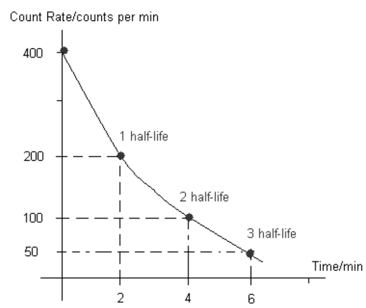
$$N = \frac{N_0}{2^n}$$

  - Where n = number of half lives.

Example

The initial activity of a radionuclide is 1MBq. What is it's half-life if after 6 half-lives have passed?

Physical Half-Life



Physical Half-Life

- ^{238}U (Uranium) : 4.47 x 10^{9} years
- ^{226}Ra (Radium) : 1600 years
- ^{99m}Tc (technetium) : 6.4 hours
- ^{140}Xe (Xenon) : 13.6 seconds
- ^{212}Po (Polonium) : 299 x 10^{-9} secs

Physical Half Life

- Longer the half life, the longer the isotope will continue to emit radiation
- Half Life REMAINS the same, no matter how many atoms present
- The Half Life and Decay Constant of a material are related!

Summary

- Nuclides
- Radioactivity
- Radioactive Decay Process
- Half-Life
- Decay Constant