Nuclear Nomenclature

Ground state: Energy tends prefers arrangements where the lowest energy state is achieved.

Radioactivity: nucleus undergos a reaction to lower its energy and become more stable

Nuclide: an atomic species with a definite number of protons and neutrons arranged in a definite order in the nucleus.

Radionuclide: nuclides that are unstable and thus decay by emission of particles or electromagnetic radiation.

Isomer: nuclides with the same number of protons and neutrons, but different energy states.

Nuclear binding energy

The energy that would be required to disassemble the nucleus of an atom into its component parts.

Mass Deficit

The mass of a nucleus is always less than the combined masses of the nucleons (protons + neutrons). The difference in mass is termed the **mass deficit**

[protons + neutrons + electrons] - [mass of atom] = [mass deficit]

The average binding energy of a nucleon = the total binding energy (calculated from the mass deficit) divided by the number of nucleons.

Radioactivity

Radioactive decay: an unstable nucleus (the parent) decays into a more stable product (the daughter).

Radioactivity (cont)

Decay energy: Nuclear energy is released as the daughter is at a lower energy level than the parent, this is in the form of particles, electromagnetic radiation (usually gamma rays) or kinetic energy

1. Particles: alpha (2 protons, 2 neutrons); beta- β+ (positive electron – positron) and β- (negative electron); Neutrons

2. Electromagnetic: gamma rays; x-rays

Total radioactive decay constant λ: a characteristic parameter for each radioactive decay process, independent of the age of the radioactive atom and is essentially independent of physical conditions

Decay rate

$$\frac{\Delta N}{\Delta t} = -\lambda N$$

$$N_t = N_0 e^{-\lambda t}$$

Decay rate/Activity

For a sample of N radioactive atoms

λ is the decay constant and has a characteristic value for each radionuclide

Physical Half-life

Time required to reduce its initial disintegration rate (activity) to one half.

Nuclide Activation

Radioactivation: Stable nuclei may be transformed into unstable radioactive nuclei by bombardment with suitable particles or photons of appropriate energy

Nuclear reactors are the main source of radionuclides used in medicine.

Activation with Thermal Neutrons

This uses neutron activation or neutron capture and produces neutron-rich unstable isotopes that decay through β− decay into more stable configurations

Two types of neutron activation processes occur commonly: (n, γ) and (n, p)

(n, γ) process results in emission of γ rays

(n, p) process results in emission of protons

This results in a mixture of stable parent nuclei and radioactive daughter nuclei. The parent act as carriers of the daughter and decrease activity.

Tc-99m is the radionuclide that is used in more than 90 percent of all nuclear medicine procedures

Activation with Protons/Heavier Charged Particles

Protons produced by **cyclotrons** are used in the production of proton-rich unstable radionuclides that decay through β+ decay or electron capture into more stable configurations.

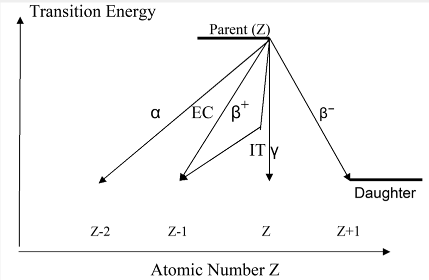
When striking a target material, protons may cause nuclear reactions that produce radionuclides in a manner similar to neutron activation in a reactor.

Because of their positive charge, protons striking the target must have high kinetic energies to penetrate the repulsive Coulomb barrier surrounding the positively charged nucleus.

Proton activation reactions are **endoergic:** energy must be supplied by the projectile for the reaction to occur.

Threshold energy: minimum energy that will allow the reaction to occur

Decay Schemes



Decay by Alpha Emission

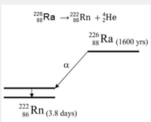
The nucleus ejects an α-particle which consists of two neutrons and two protons (^{4}He nucleus)

It is a ‘massive’ particle absorbed ~ 0.03 mm in body tissues

Common among very heavy elements.

The daughter is often in an excited state resulting in the emission of gamma rays.

Alpha Decay



Decay by β− Emission

When a radionuclide is neutron rich (that is, it has more neutrons than the stable isotope), it decays by the emission of a beta particle (β) and an antineutrino.

a neutron is converted into a proton so that the atomic number Z of the product increases by one.

A β particle is also an electron

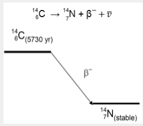
A β particle originates from within the nucleus whereas an electron originates from the extranuclear electron orbitals.

Antineutrino: a particle which is is non-reactive, has no charge and essentially no mass

Decay by β− Emission (cont)

The beta particle and the antineutrino are ejected from the nucleus with kinetic energy equal to the energy released in the process (ie. they carry away some of the energy released in the decay process)

β− Decay

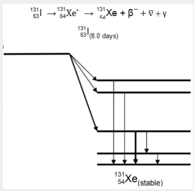


Decay by (β-, γ) Emission

Decay by beta emission can result in a daughter nucleus in an excited state

This excited state will decay to the ground state by the emission of γ-rays as the nucleons fall to a lower energy state.

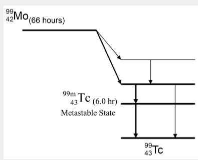
(β-, γ) Decay



Isomeric Transition (IT)

A daughter nucleus may be formed in a 'long-lived' **metastable state**, hen decay by the emission of a γ-ray.

Isomeric Transition Decay



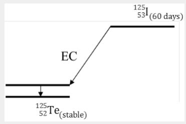
Electron Capture (EC) and (EC,γ) Decay

When a radioactive nucleus has fewer neutrons than its stable isotope, it can undergo decay by electron capture

An orbital electron is 'captured' by the nucleus and combines with a proton to form a neutron.

The daughter product is often in an excited or metastable state, therefore gamma rays may also be emitted.

Electron Capture



Positron (β+) and (β+,γ) Decay

Neutron-deficient (proton-rich) radionuclide

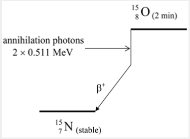
A proton is converted to a neutron, a positron and a neutrino, thus decreasing the atomic number of the daughter nuclide by one.

The β+ particle (positron) collides with an ordinary electron in an annihilation reaction in which the combined mass is converted into energy.

The energy appears in the form of two annihilation photons (each 0.511 MeV) travelling in opposite directions (180° apart).

The daughter may be left in an excited state resulting in additional γ-rays being emitted, i.e. (β+,γ) decay.

Positron (β+) and (β+,γ) Decay



β+ Decay and Electron Capture

Positron emission and electron capture have the same effect on the parent nuclide, they reach the same endpoint
If the decay is by electron capture, then either x-rays or Auger electrons will be emitted, not positrons.
Positron decay occurs more frequently among lighter elements
Electron capture is more frequent among heavier elements where orbital electrons are closer to the nucleus and more easily captured.
Some radionuclides can decay by either mode and the percentage for each process is fixed for a given radionuclide.

β+ Decay and Electron Capture