FUNDAMENTALS OF RADIATION - Study Material

The atom can be thought of as a system containing a positively charged nucleus and negatively charged electrons which are in orbit around the nucleus.

The nucleus is the central core of the atom and is composed of two types of particles: *protons* which are positively charged, and *neutrons* which have a neutral charge. Each of these particles has a mass of approximately one atomic mass unit (amu). (1 amu = 1.66E-24 g)

Electrons surround the nucleus in orbitals of various energies. (In simple terms, the farther an electron is from the nucleus, the less energy is required to free it from the atom.) Electrons are very light compared to protons and neutrons. Each electron has a mass of approximately 5.5E-4 amu.

A nuclide is an atom described by its atomic number (Z) and its mass number (A). The Z number is equal to the charge (number of protons) in the nucleus, which is a characteristic of the element. The A number is equal to the total number of protons and neutrons in the nucleus. Nuclides with the same number of protons but with different numbers of neutrons are called isotopes.

For example, deuterium (2,1H) and tritium (3,1H) are isotopes of hydrogen with mass numbers two and three, respectively. There are on the order of 200 stable nuclides and over 1100 unstable (radioactive) nuclides. Radioactive nuclides can generally be described as those which have an excess or deficiency of neutrons in the nucleus.

Radioactive decay

Radioactive nuclides (also called radionuclides or radioisotopes) can regain stability by nuclear transformation (radioactive decay) emitting radiation in the process. The radiation emitted can be particulate or electromagnetic or both. The various types of radiation and examples of decay are shown below.

Alpha particles (α)

Alpha particles have a mass and charge equal to those of helium nuclei (2 protons + 2 neutrons). Alpha particles are emitted during the decay of some very heavy nuclides (Z > 83).

226,88Ra --> 222,86Rn + 4,2a

Beta particles (β^+ β^-)

Beta particles are emitted from the nucleus and have a mass equal to that of electrons. Betas can have either a negative charge or a positive charge. Negatively charged betas are equivalent to electrons and are emitted during the decay of neutron rich nuclides.

14,6C --> 14,7N + 0,-1B + neutrino

Positively charged betas (positrons) are emitted during the decay of proton rich nuclides.

22,11Na --> 22,10Ne + 0,1B + g

Gamma rays (γ)

Gamma rays (also called gammas) are electromagnetic radiation (photons). Gamma rays are emitted during energy level transitions in the nucleus. They may also be emitted during other modes of decay.

99m,43Tc --> 99,43Tc + g

Electron capture

In certain neutron deficient nuclides, the nucleus will capture an orbital electron resulting in conversion of a proton into a neutron. This type of decay also involves gamma emission as well as x-ray emission as other electrons fall into the orbital vacated by the captured electrons.

125,53I + 0,-1e --> 125,52Te + g

Neutrons (n)

For a few radionuclides, a neutron can be emitted during the decay process.

17,7N --> 17,8O* + 0,-1B (*excited state)
17,8O* --> 16,8O + 1,0n

X-rays

X-rays are photons emitted during energy level transitions of orbital electrons. Bremsstrahlung x-rays (braking radiation) are emitted as energetic electrons (betas) are decelerated when passing close to a nucleus. Bremsstrahlung must be considered when using large activities of high energy beta emitters such as P-32 and S-90.

Characteristics of radioactive decay

In addition to the type of radiation emitted, the decay of a radionuclide can be described by the following characteristics.

Half-life

The half-life of a radionuclide is the time required for one-half of a collection of atoms of that nuclide to decay. Decay is a random process which follows an exponential curve. The number of radioactive nuclei remaining after time (t) is given by:

$A = A_o/(2^N)$ » $N = t / T^*$
where
A_o = original number of atoms
A = number remaining at time t
t = decay time
T = half-life of the radioisotope
* = same units must be maintained