Radioactive Decay

Radioactive decay occurs in atoms where the force of electrical repulsion in the nucleus is greater than the attractive force of the strong nuclear force. In this process, the nucleus essentially changes in one of 5 ways, resulting in a changed nucleus, known as a ***daughter nucleus***. (The original nucleus is known as a ***parent nucleus***). This changing of one element into another is known as ***transmutation***.

Alpha Decay

The first form of decay is ***alpha (α-) decay***. In this process, the nucleus emits an α-particle, which is essentially the nucleus of a helium atom (^4_2He).

$$^{A}_{Z}N \rightarrow {}^{A-4}_{Z-2}N' + {}^{4}_{2}He$$

Any element with an $Z > 82$ is unstable and thus can be considered as "radioactive"

Disintegration Energy (Q)

$Q = (M_p - M_D - m_\alpha)\, c^2$ $= -\Delta m c^2$

Example with Polonium-14

$^{214}_{84}Po \rightarrow {}^{210}_{82}Pb + {}^{4}_{2}He + \text{energy}$

$^{214}_{84}Po$ → $213.995177\,u$

$^{210}_{82}Pb$ → $209.984163\,u$

$^{4}_{2}He$ → $4.002602\,u$

$$Q = (213.995177\,u - 209.984163\,u - 4.002602\,u) \cdot \left(931.5 \frac{MeV}{u}\right)$$

$$= 7.835778\ MeV$$

Beta Decay (β^-)

In beta β^- decay, the nucleus emits an electron when it decays (this electron is called a β^- particle). It should be noted that this β^- particle is not an orbital electron, but is created within the nucleus. In the process, a neutron disintegrates into a proton, electron and a ***antineutrino***.

Neutrino: ν (Greek nu)
Antineutrino: $\bar{\nu}$

$$^{A}_{Z}N \rightarrow {}^{A}_{Z+1}N' + e^- + \bar{\nu}$$

Nuclei which undergo β^- decay are nuclei which have too many neutrons for the number of protons
(e.g. $^{14}_{6}C$).

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + e^- + \bar{\nu} + \text{energy}$$

$^{14}_{6}C$: 14.003242u
$^{14}_{7}N$: 14.003074u

$$Q = (14.003242u - 14.003074u)\left(931.5\frac{MeV}{u}\right)$$
$$= 0.156492\ MeV$$

Positron (β+) Decay

Like β^- decay, β^+ decay occurs by the emission of a positively charged electron (known as a positron, e^+) The positron is the ***antiparticle*** of the electron, because it has the same properties as an electron but opposite charge (and some other quantum conditions). These are nuclei which have too few neutrons for the number of protons (e.g. $^{19}_{10}Ne$).

$$^{A}_{Z}N \rightarrow {}^{A}_{Z-1}N' + \beta^+ + \nu$$

Note: When using atomic masses, we must account for the difference in the number of electrons of the atoms in both forms of beta decay.

Electron Capture (K-capture)

In this case, an electron is absorbed into the nucleus (usually from the innermost K-shell, hence K-capture). In this case, the daughter nucleus is produced with a neutrino. It is inferred by the detection of X-rays as the electrons jump down to fill the empty shell and the production of new nuclei

$$ {}^{A}_{Z}N + e^{-} \rightarrow {}^{A}_{Z-1}N' + \nu $$

Gamma (γ) Decay

Gamma decay occurs when a nucleus is in an excited state (it could arrive in this state by some previous decay). This excited state is said to be a ***metastable state*** and the nucleus is said to be an ***isomer***. In this case, the nucleus drops to a lower state (or ground state) and emits a γ-ray.

$$ {}^{A}_{Z}N^{*} \rightarrow {}^{A}_{Z}N + \gamma $$