β^+ decay

For nuclides having N/Z too small, they emit a e^+ for stability.

The basic process is:

$$p \rightarrow n + \beta^+ + \nu_e$$

β^+ decay can occur wherever the mass of the original neutral atom is at least two e^- masses larger than that of the final atom.

e^- capture

There are a few nuclides for which β^+ emission is not energetically possible but in which an orbital $\bar{e}$ (usually in the K shell) can combine with a proton in the nucleus to form a n and a ν_e. The n stays in the nucleus and ν_e is emitted. The basic process is:

$$p + \beta^- \rightarrow n + \nu_e$$ ← This reaction also helps to explain the formation of neutron stars.

e^- capture can occur wherever the mass of the original neutral atom is larger than that of the final atom.

Note that <u>all</u> these three β decays occur within a nucleus.

β^- decay can also occur outside the nucleus

β^+ decay is forbidden by conservation of mass-energy for a p outside nucleus.

The $\bar{e}$ capture can occur outside the nucleus only with the addition of some extra energy, in a collision.

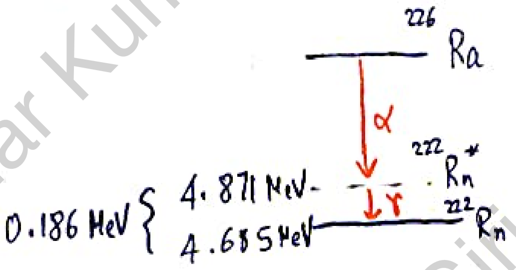
γ Decay

Nucleus being trapped in a potential well has quantized set of energy levels. In ordinary physical & chemical transformations the nucleus is always in its grand state. When a nucleus is placed in an excited state either by bombardment with high-energy particles or by radioactive transformation, it can decay into the grand state by emission of one or more photons with typical energies: 10 keV – 5 MeV, therefore they are in the gamma rays spectrum.

Ex: Recall ^{226}Ra α-decay, in one of the decay channels we had

$$^{226}Ra \rightarrow {}^{222}Rn^{*} + \alpha \rightarrow \underbrace{^{222}Rn}_{} + \alpha + \gamma$$

Radon (more on this later!)



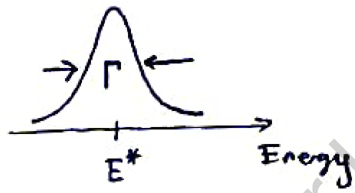
In the γ decay, the element does not change; the nucleus merely goes from an excited state to a less excited state.

Width vs. Lifetime

An excited (nuclear) state has a finite lifetime within which it decays to a lower state. According to the energy-time uncertainty principle, if an average nucleus survives in an excited state only for the lifetime τ of the state, then its energy in the state can be specified only within an energy range Γ,

$$\Gamma = \frac{\hbar}{\tau}$$

Excited states are, therefore, not perfectly sharp.



Ex: A typical γ-decaying state has a lifetime $\tau \sim 10^{-10}$ s.

$$\Gamma = \frac{\hbar}{\tau} \sim \frac{10^{-15}\ \text{eV.s}}{10^{-10}} = 10^{-5}\ \text{eV}$$

In comparison to the typical energy $E = 1$ MeV of such a state, Γ is extremely small.

$$\frac{\Gamma}{E} \sim 10^{-11}$$

This minute value of the ratio will lead to a remarkably accurate solid-state spectroscopic technique, Mössbauer spectroscopy with a sensitivity of a few parts in 10^{11} (which follows from above consideration).