Nuclear Decays: An Introduction

By

Dr. Mahendra Singh

Deptt. of Physics

Brahmanand College, Kanpur

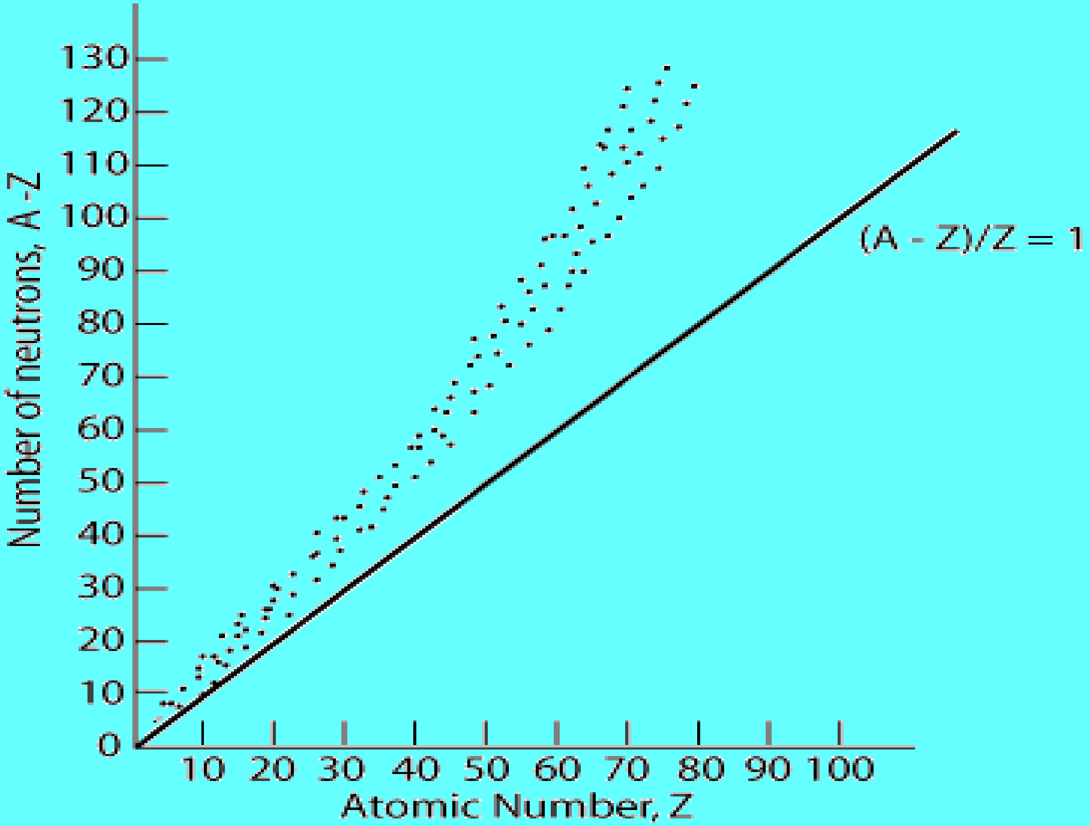
Nuclear Decay

Radioactive decay is the process in which an unstable ***atomic nucleus*** loses energy by ***emitting radiation*** in the form of ***particles or electromagnetic waves*****.**

There are numerous types of radioactive decay. The general idea:

An unstable nucleus releases energy to become more stable

The Nuclear Stability Belt



Types of Nuclear Decay

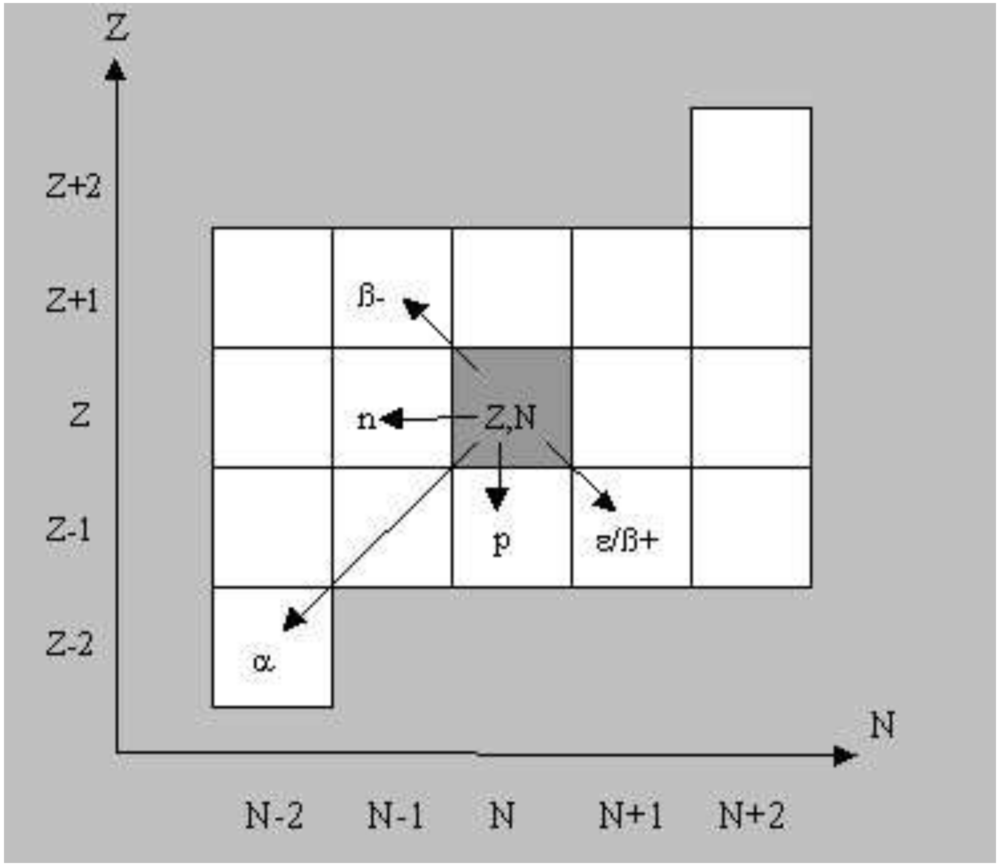
- The type of radioactive decay depends on the particular type of nuclear instability (whether the neutron to proton ratio is either too high or too low) and on the mass-energy relationship among the parent nucleus, daughter nuclear, and emitted particle.

$$X \rightarrow Y + y + Q$$

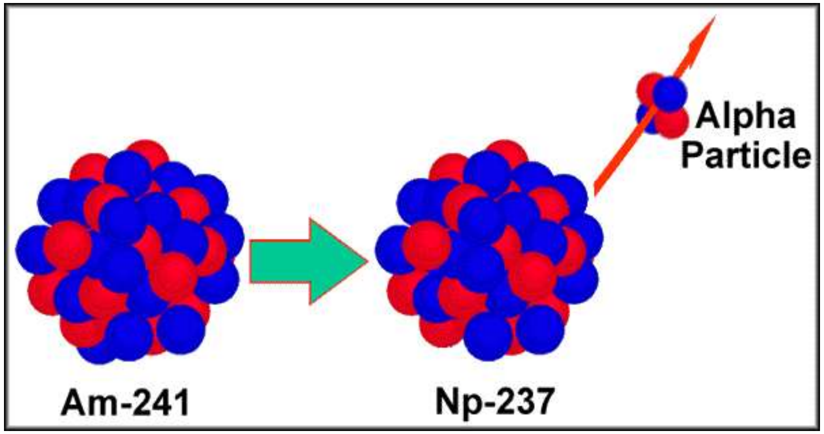
$$Q = \left[M_{X,N} - M_{Y,N} - M_{y,N} \right] c^2$$

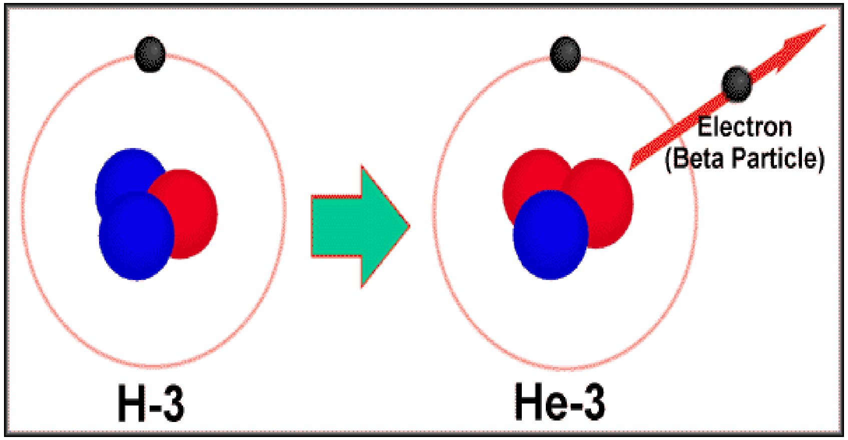
Four Types of Radioactive Decay

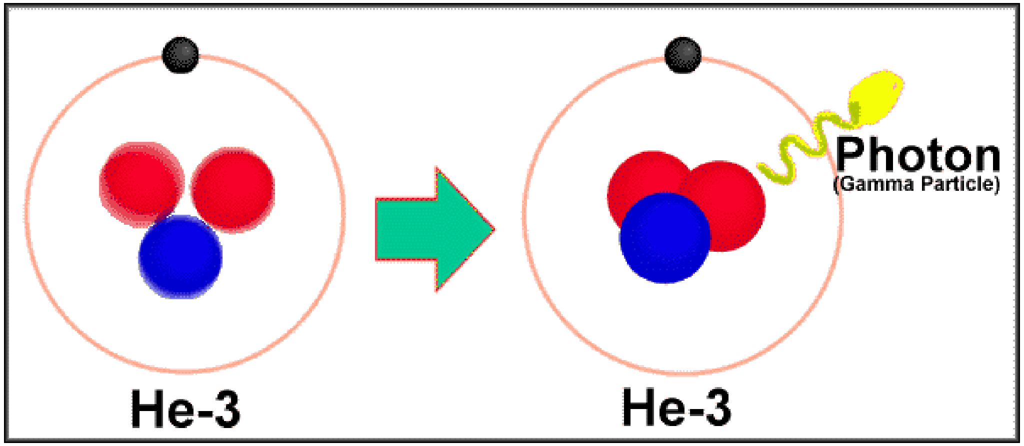
1) Alpha (α) decay - ^{4}He nucleus (2p + 2n) ejected
2) Beta (β) decay - change of nucleus charge, conserves mass
3) Gamma (γ) decay - photon emission, no change in A or Z
4) Spontaneous fission - for Z=92 and above, generates two smaller nuclei



Common Types of Radioactive Emissions







Summary of Radioactive Decay Processes			
Type of Radioactive Decay	Particle Emitted	Change in Mass Number	Change in Atomic Number
Alpha Decay	Helium Nuclei	Decreases by 4	Decreases by 2
Beta Decay	Beta Particle	No Change	Increases by 1
Gamma Emission	Energy	No Change	No Change
Positron Emission	Positron	No Change	Decreases by 1
Electron Capture	X-ray Photon	No Change	Decreases by 1

Alpha Decay

- Heavy nuclei with mass numbers higher than 150 can disintegrate by emission of an Alpha Decay

- Involves strong and coloumbic forces
- Alpha particle and daughter nucleus have equal and opposite momentums (i.e. daughter experiences "recoil")

$${}^{A}_{Z}X \qquad {}^{A-4}_{Z-2}Y \qquad {}^{4}_{2}He$$

$$\mathbf{Q = (M_X - M_Y - M_\alpha)c^2 > 0}$$

$$KE_\alpha \approx [(A-4)/A]Q \qquad \approx 4 - 9\ \text{MeV}$$

Discrete Energy Spectrum

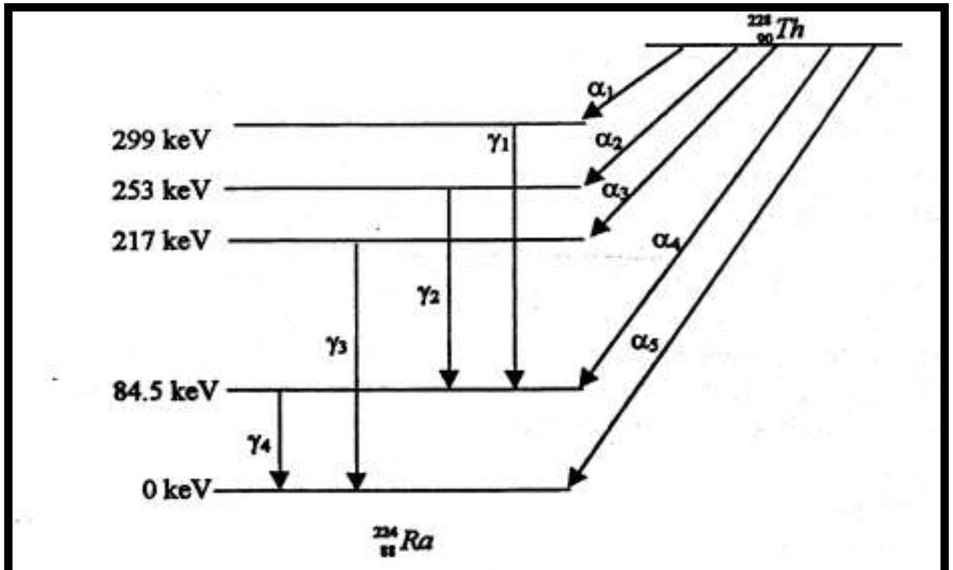


Fig.5.2: Decay of $^{228}_{90}Th \rightarrow ^{224}_{88}Ra + \alpha$

Alpha Decay-Barrier Penetration

- One of the first applications of QM was by Gamow who modeled alpha decay by assuming the alpha was moving inside the nucleus and had a probability to tunnel through the Coulomb barrier
- from 1D thin barrier (460) for particle with energy E hitting a barrier potential V and thickness gives Transmission = T

$$T = 16\frac{E}{V}(1-\frac{E}{V})e^{-2ka}$$

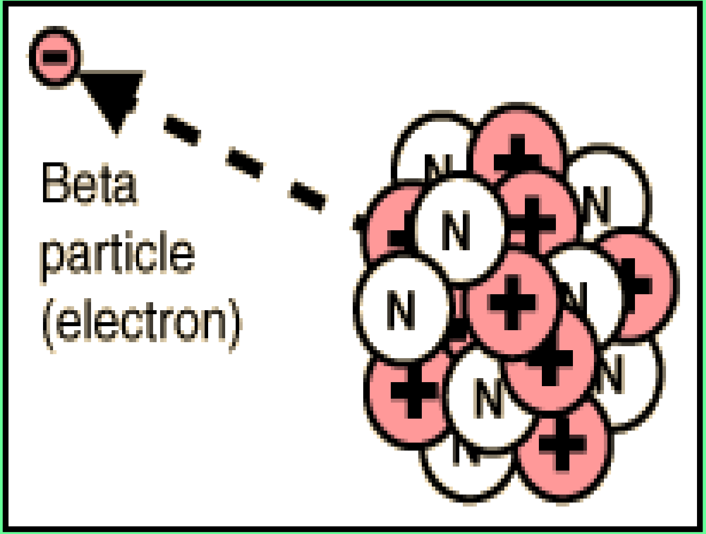
$$k = \frac{\sqrt{2m(V-E)}}{\hbar}$$

- now go to a Coulomb barrier V= A/r from the edge of the nucleus to edge of barrier and integrate- each dr is a thin barrier

$$T \approx \exp(-2\int_{r_n}^{r_c}\sqrt{\frac{2m}{\hbar^2}(\frac{2Ze^2}{4\pi\varepsilon_0 r}-E)}\,dr \qquad r_c = \frac{2Ze^2}{4\pi\varepsilon_0 K_\alpha}$$

Beta Decay

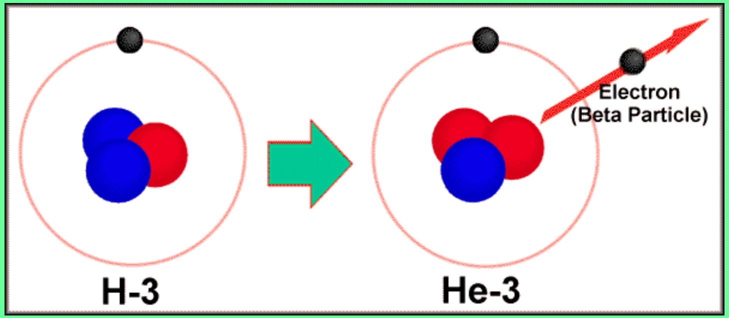
- **Beta particles are just electrons from the nucleus, the term "beta particle" being an historical term used in the early description of radioactivity. The high energy electrons have greater range of penetration than alpha particles, but still much less than gamma rays.**



The emission of the electron's antiparticle, the positron, is also called beta decay.

β Decay - Two Types

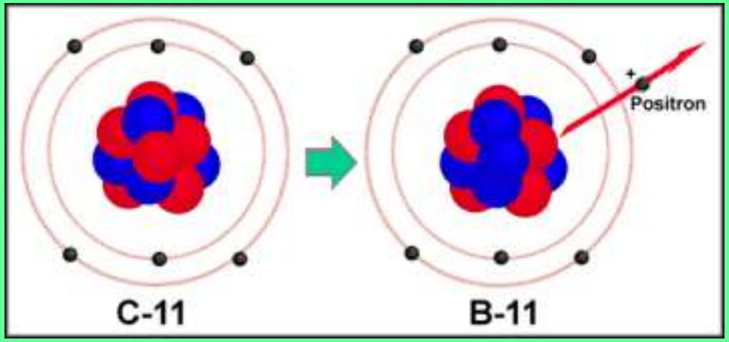
1) β⁻ Decay



$$^{3}_{1}H \xrightarrow{\beta} {}^{3}_{2}He + e^{-} + \bar{\upsilon}_e$$

- converts one neutron into a proton and electron
- no change of A, but different element
- release of anti-neutrino (no charge, no mass)

2) β+ Decay



$$^{11}_{6}C \xrightarrow{\beta^{+}} {}^{11}_{5}B + e^{+} + \upsilon_e$$

-converts one proton into a neutron and a positron
- no change of A, but different element
- release of neutrino

Beta Decay

$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e + {}^{0}_{0}\bar{\nu} $$

$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e + {}^{0}_{0}\nu $$

$$ \mathbf{Q = (M_X - M_Y - M_e)c^2 > 0} $$

↓

Continuous Energy Spectrum

Continuous Beta Energy Spectrum

Features of the Spectra:

➢Beta particles have continuous distribution of energy from 0 to E**max.**

➢Most of the beta particles have energy one third of end point energy.

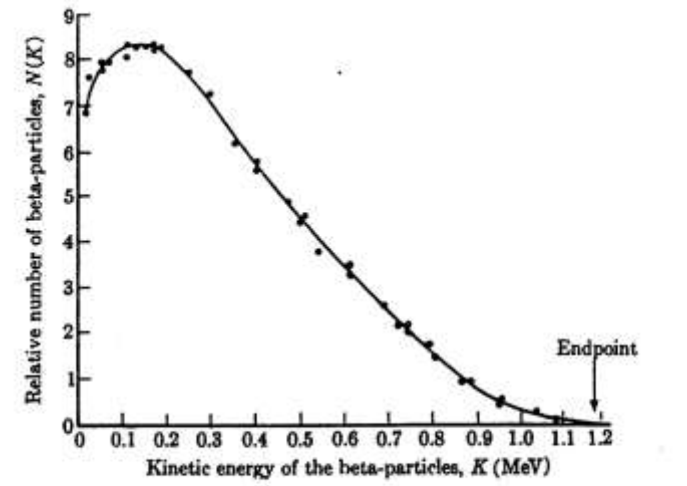


Fig. 5.2: A typical kinetic energy spectrum of beta particles

Difficulties of Explaining the continuous Spectra

1. Theoretically all beta particles must be emmited with same energy but experimentally it does not occur. Where the remaining energy goes?
2. Non Conservation of angular momenta.
3. Non conservation of linear momenta.

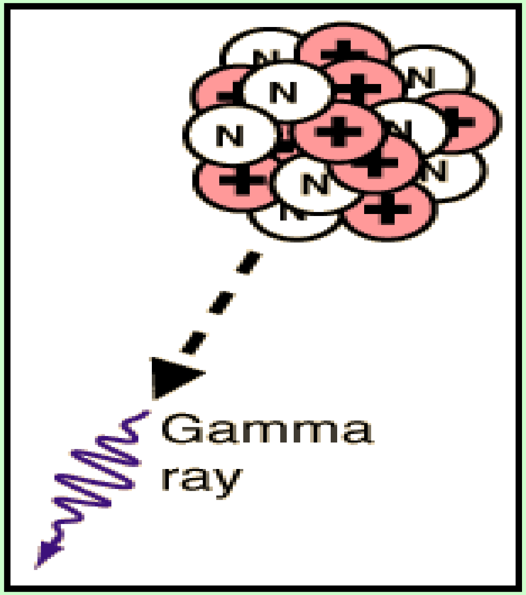
→

The problem was solved by Pauli in 1930 who suggested that a spin ½,massless particle must be emmited along with electron.

The particle is called neutrino

Gamma Decay

•Sometimes the newly formed isotopes (after alpha or beta decay) appear in the excited state (with a surplus of energy). Excited nuclides have tendency to release the excess of energy by emission of gamma rays (Photons) and return to their ground state.



- **Gamma radioactivity is composed of electromagnetic rays. It is distinguished from x-rays only by the fact that it comes from the nucleus. Most gamma rays are higher in energy than x-rays and therefore are very penetrating.**

$$ {}^{A}_{Z}X^{*} \longrightarrow {}^{A}_{Z}X + {}^{0}_{0}\gamma $$

Discrete Energy Spectrum

Gamma Ray Spectra

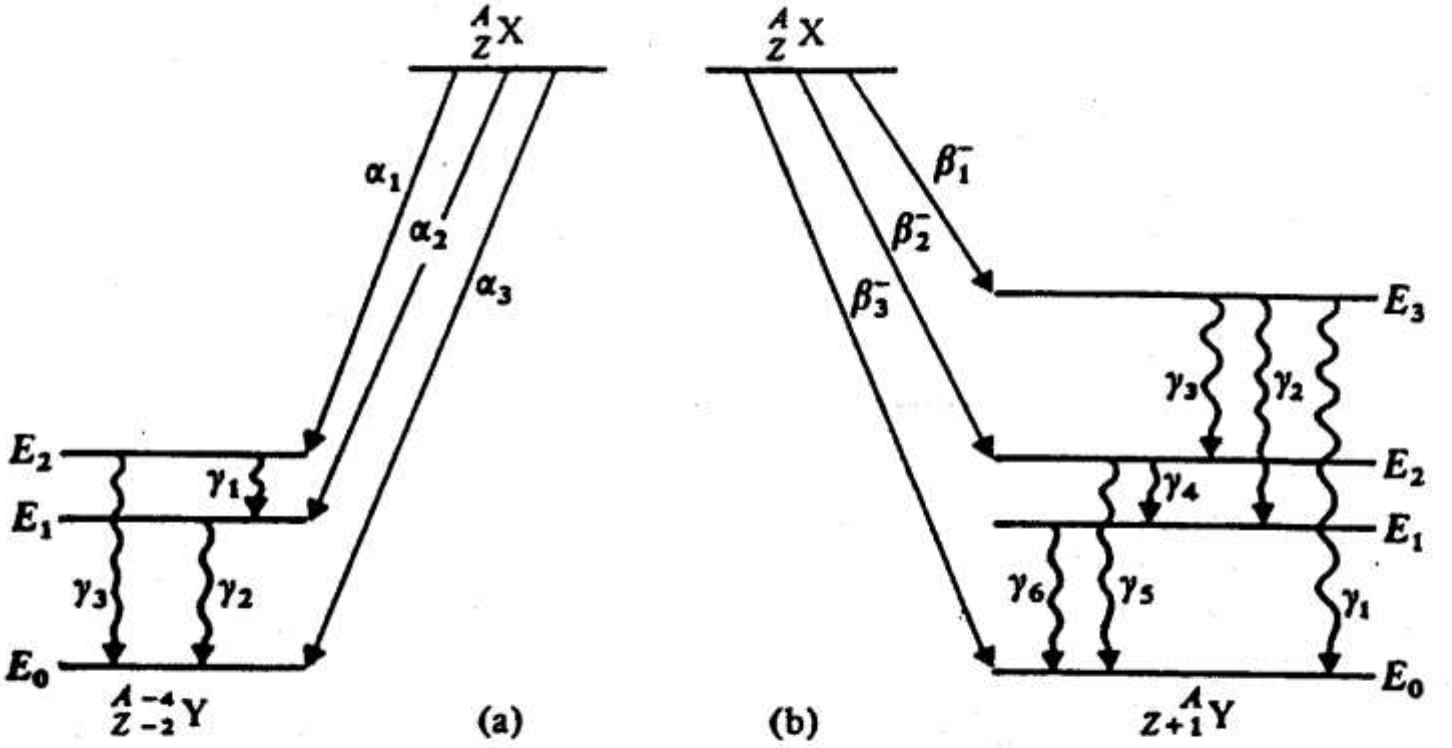


Fig. 5.4: Gamma emissions following α and β decays of a nucleus $^A_Z X$

Electron Capture

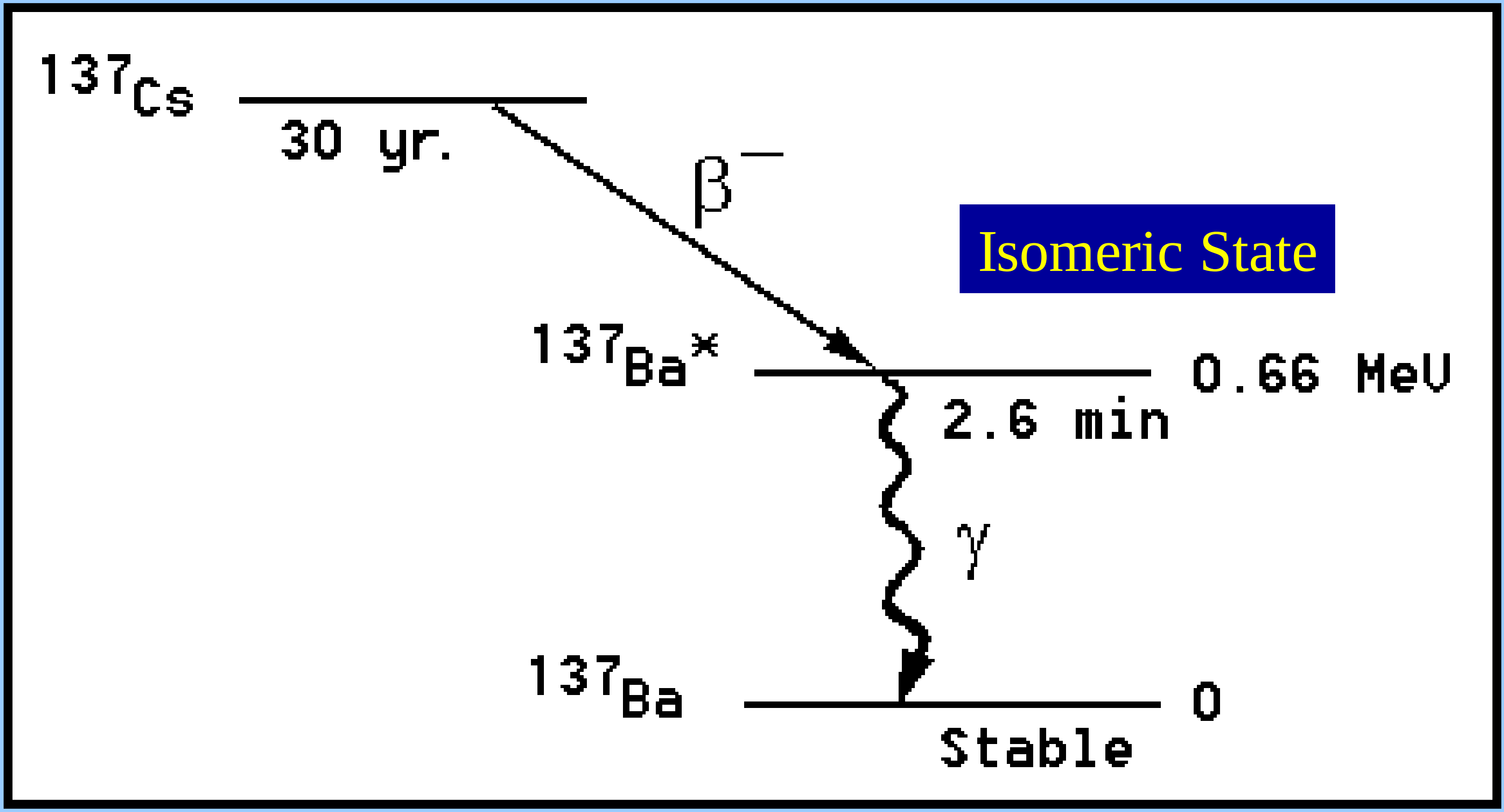
- **Electron capture is one form of radioactivity. A parent nucleus may capture one of its orbital electrons and emit a neutrino. This is a process which competes with positron emission and has the same effect on the atomic number. Most commonly, it is a K-shell electron which is captured, and this is referred to as K-capture.**

- A typical example is:

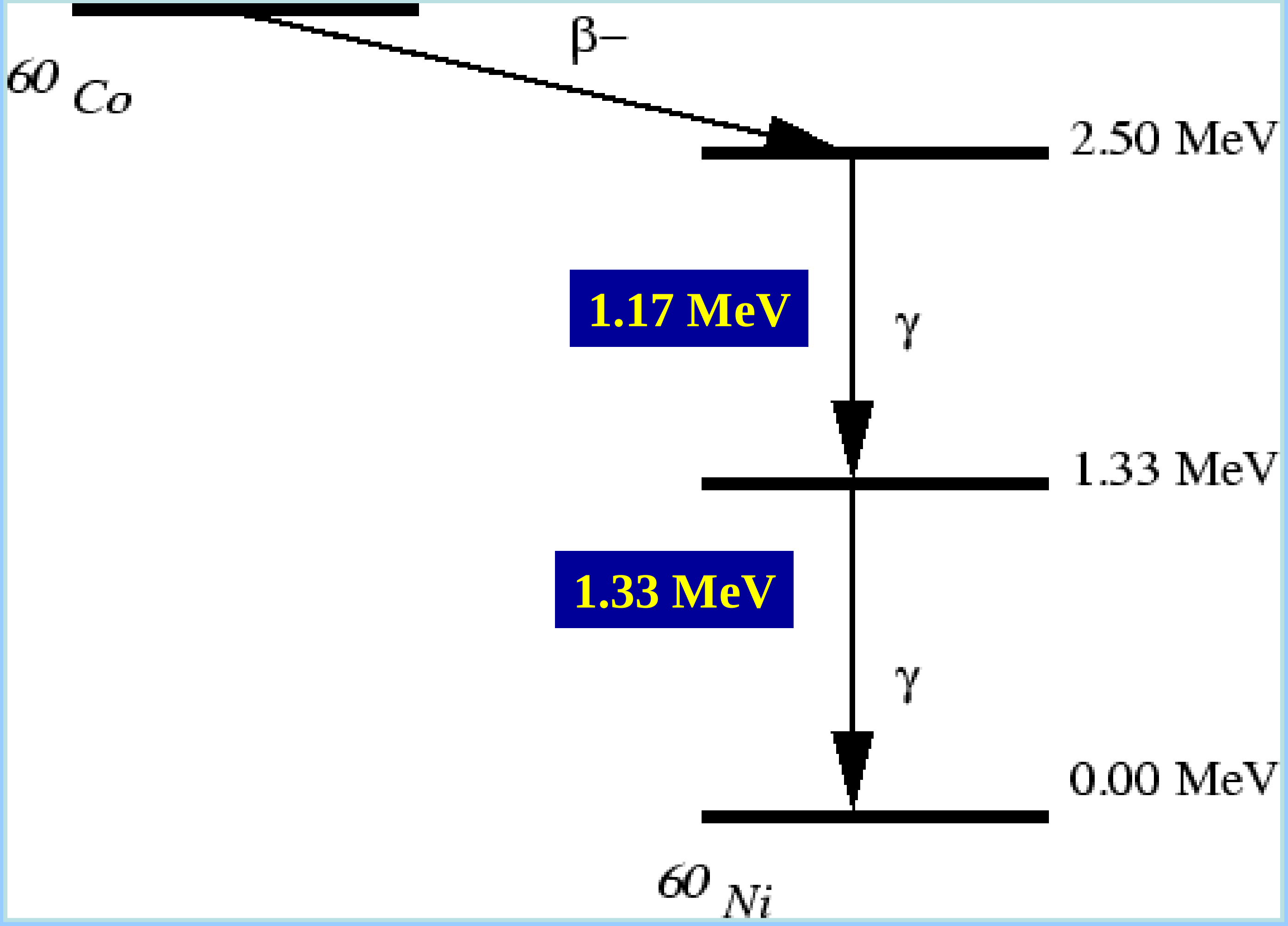
$$^{7}_{4}Be + {}^{0}_{-1}e \longrightarrow {}^{7}_{3}Li + \nu$$

$$Q = (M_X + M_e - M_Y)c^2 > 0$$

^{137}Cs Decay


137Cs
30 yr.
β−
Isomeric State
137Ba*
0.66 MeV
2.6 min
γ
137Ba
0
Stable

^{60}Co Decay



Thank YOU