Exotic Decay Modes (i.e. rare)

Usually involve nuclei far from stability or very heavy nuclei

A. Spontaneous Fission

$$ {}^{A}_{Z}X \rightarrow {}^{A_1}_{Z_1}B + {}^{A_2}_{Z_2}C + Q_{SF} $$

$$ A_1 \approx A_2 \sim A/2 $$
$$ Z_1 \approx Z_2 \sim Z/2 $$

1. Mass Split

Asymmetric due to influence of nuclear shells; e.g. ${}^{132}_{50}Sn_{82}$

Example:

$$ {}^{252}_{98}Cf \xrightarrow{2.5y} {}^{140}_{54}Xe^{*} + {}^{112}_{44}Ru^{*} + Q_{SF} $$

Q_{SF}~190 MeV

β^-, γ ↓ STABLE

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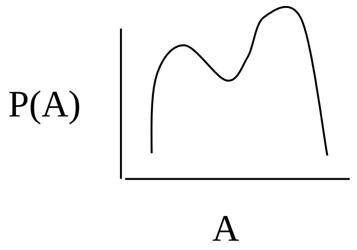
2. Mass Yield Curve



i.e., NO SPECIFIC EQUATION Since there are **many ways** the nucleus can divide, all of which move up <BE> curve. Problem: nuclear waste management

3. Q_{SF}: Energy Release

a. Most of the energy goes into the kinetic energy of the fragments.
b. Remainder goes into heating fragments (~10%)

Bad news: copious γ and β emission

4. Occurrence: A > 230

Examples: $^{232}_{90}Th(t_{SF} = 10^{18}\, y)$ $^{258}_{100}Fm(t_{SF} = 0.4 s)$

SF limits heavy element production in both nature and laboratory

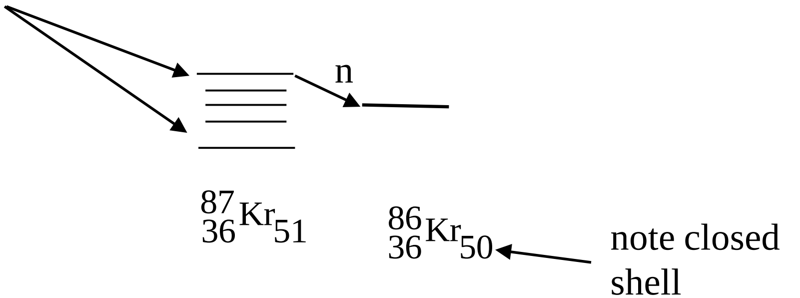
5. Barrier Penetration Problem: hard to get big chunks of matter to separate unless Z is very large (large Coulomb repulsion). Odd nucleons slow down rate; most new elements > 106 are odd-A

Cluster Decay

^{14}C, ^{18}O, ^{22}Ne have been observed from $_{88}Ra$, $_{90}Th$ and $_{92}U$ isotopes
Produces products near Z = 82, N = 126 closed shells.

Delayed Proton and Neutron Decay

1. Decay of highly neutron- or proton-rich nuclei
2. Binding energies must be low; usually from excited states with $E^* > B_p$ or B_n



D. **Double Beta Decay**

Simultaneous Emission of two β^- particles ; i.e., e – e $\Rightarrow$ e-e

$$^{130}_{52}\text{Te} \rightarrow {}^{130}_{54}\text{Xe} + 2\,{}^{\beta^-}_{-1} + 2\,\bar{\nu} + Q_{2\beta^-} \quad ; \; Q_{2\beta^-} \quad \text{Large}$$

$$t_{1/2} \gtrsim 10^{21}\text{y}$$

Summary of Decay Modes.

1. Alpha decay

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

$$Q_\alpha = [M(X) - M(Y) - M(He)]c^2$$

$A > 140$

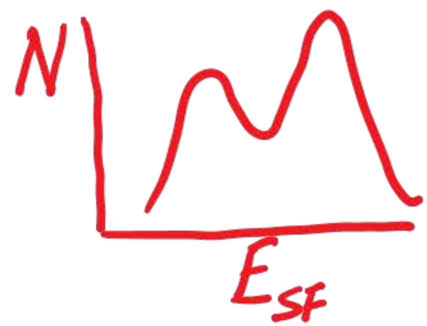
$10^{-21}s < t_{1/2} < \infty$

STRONG

2. Spontaneous Fission

$${}^{A}_{Z}X \longrightarrow {}^{A/2}_{Z/2}Y$$

$$Q_{SF} = [M(X) - 2M(Y)]c^2$$



$A > 230$

$10^{-21}s < t_{1/2} < \infty$

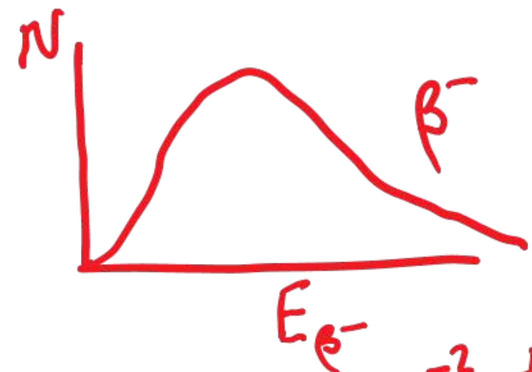
STRONG

3. Beta decay.

a. Negatron

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

$$Q = [M(X) - M(Y)]c^2$$



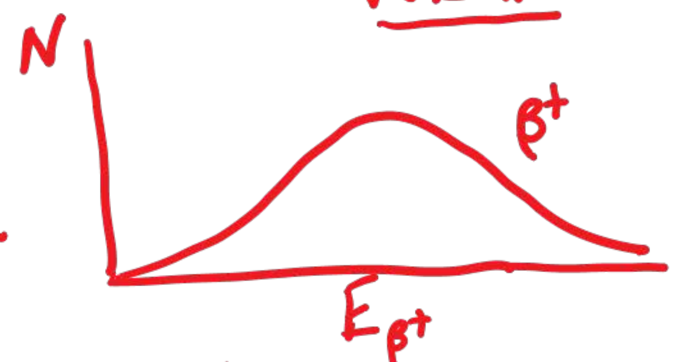
$10^{-2}s < t_{1/2} < \infty$

<u>WEAK</u>

b. Positron

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

$$Q = \left[M(X) - M(Y) - \frac{1.022\ \text{MeV}}{c^2}\right]c^2$$

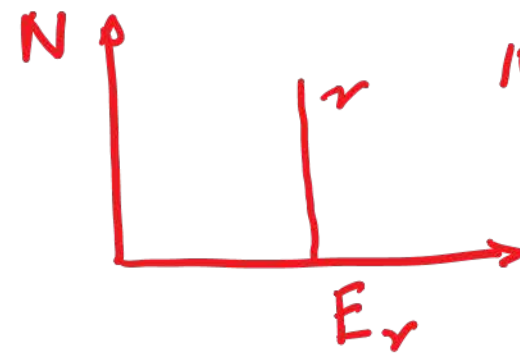


$10^{-2}s < t_{1/2} < \infty$

3 c. Electron capture

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

$$Q = [M(X) - M(Y)]c^2$$



$10^{-2}\,s < t_{1/2} < \infty$

WEAK

4. Gamma decay.

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

Internal Conversion $\longrightarrow {}^{A}_{Z}X^{+} + e^{-}$

Pair Production $\longrightarrow {}^{A}_{Z}X + \beta^{-} + \beta^{+}$

discrete

$10^{-12}\,s < t_{1/2} < \infty$

ELECTROMAGNETIC

$$Q_{\gamma} = h\nu$$

$$Q_{\gamma} = E_{e^-} + B.E.(e^-)$$

$$Q_{pp} = E_{\beta^+} + E_{\beta^-} + 1.022\ \text{MeV}.$$