8.701

Introduction to Nuclear and Particle Physics

Markus Klute - MIT
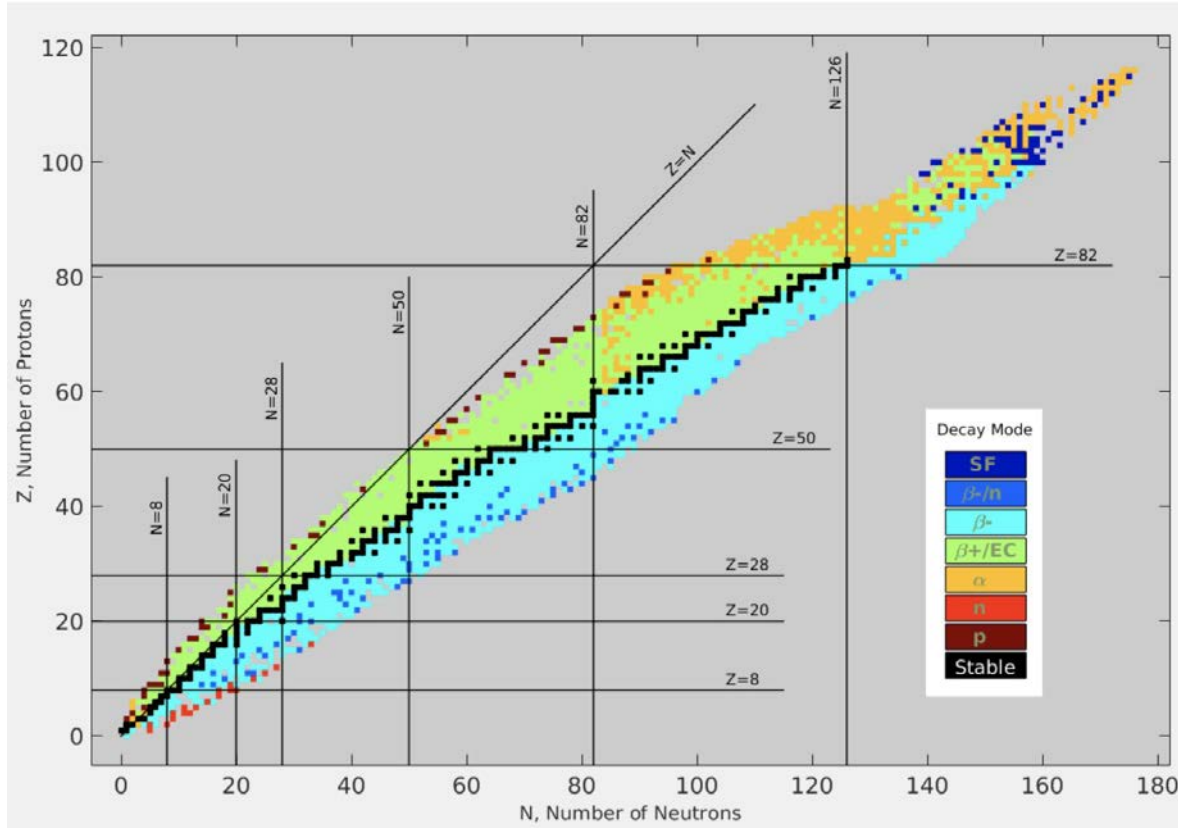
9. Nuclear Physics

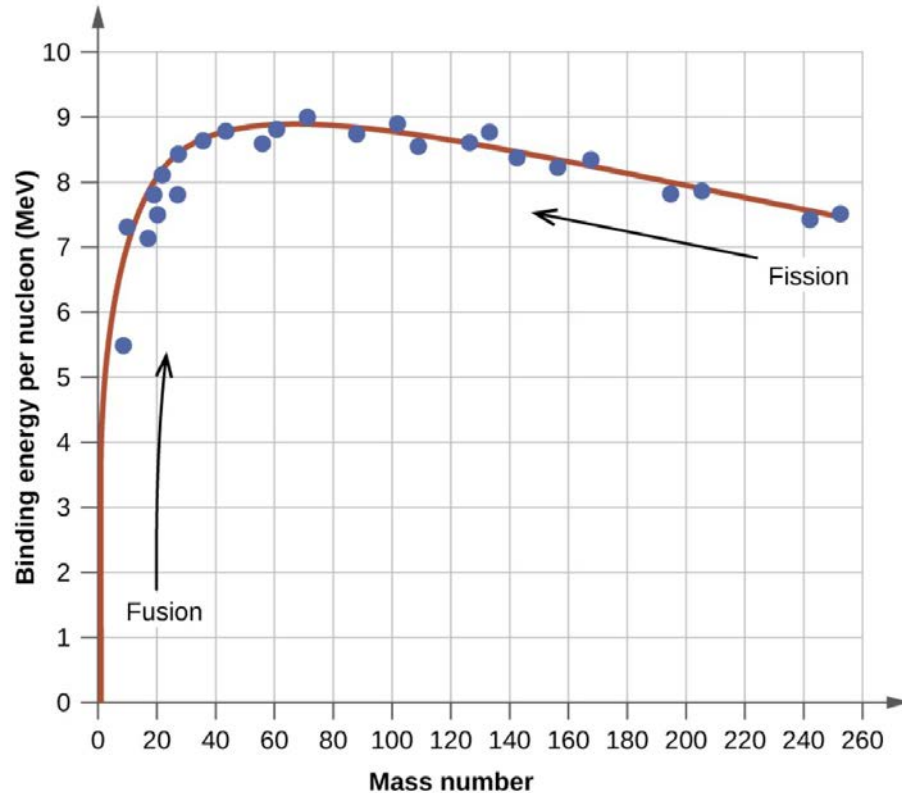9.3 Stability

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Valley of Stability

Fusion and Fission

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Nuclear Decays

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Alpha

Beta
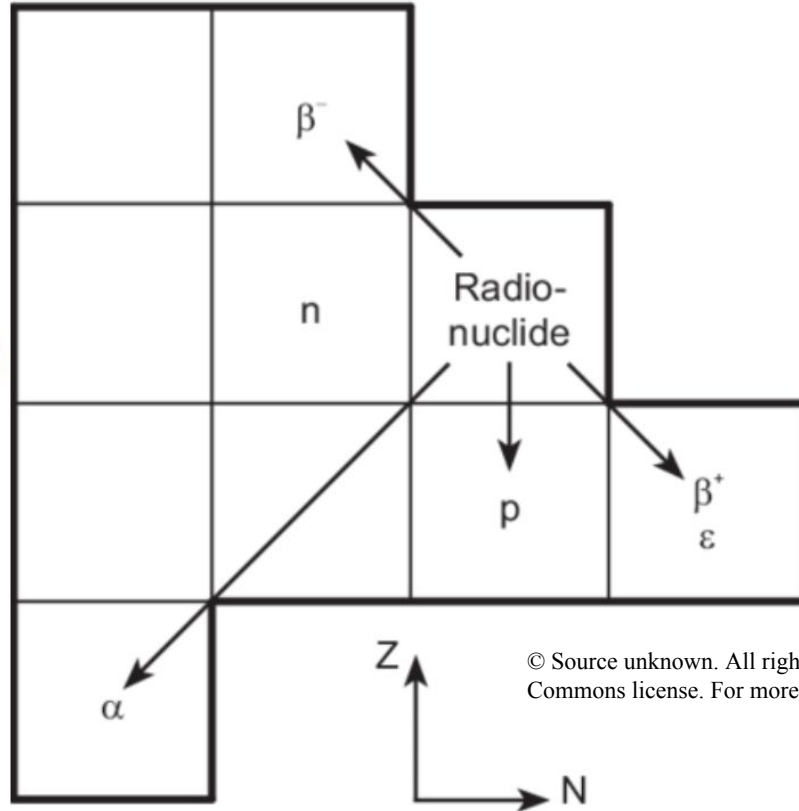
Alpha Decay

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α Particle
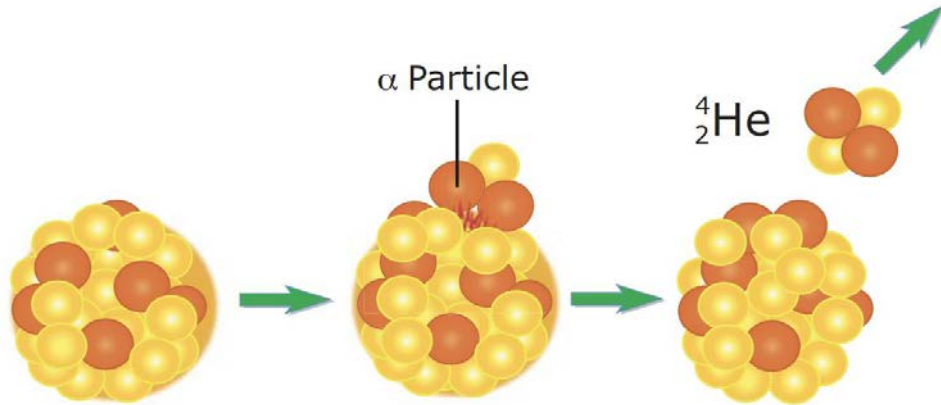
$^{4}_{2}$He

Alpha Decay

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Range of lifetimes are 10ns to 10^{17} years
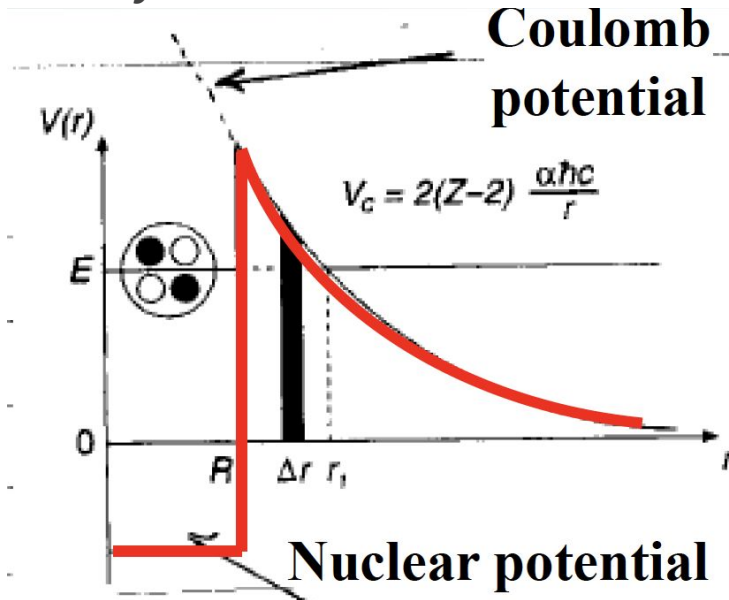
Coulomb potential

$$V_c = 2(Z-2)\frac{\alpha \hbar c}{r}$$

Nuclear potential

$V(r)$

E

$\ln\left(t_{\frac{1}{2}}\right)$

$\frac{1}{\sqrt{E_\alpha}}$

Cm
Pu
U
Fm
Cf
Th
Ra
Em
Po

E_α(MeV)

6
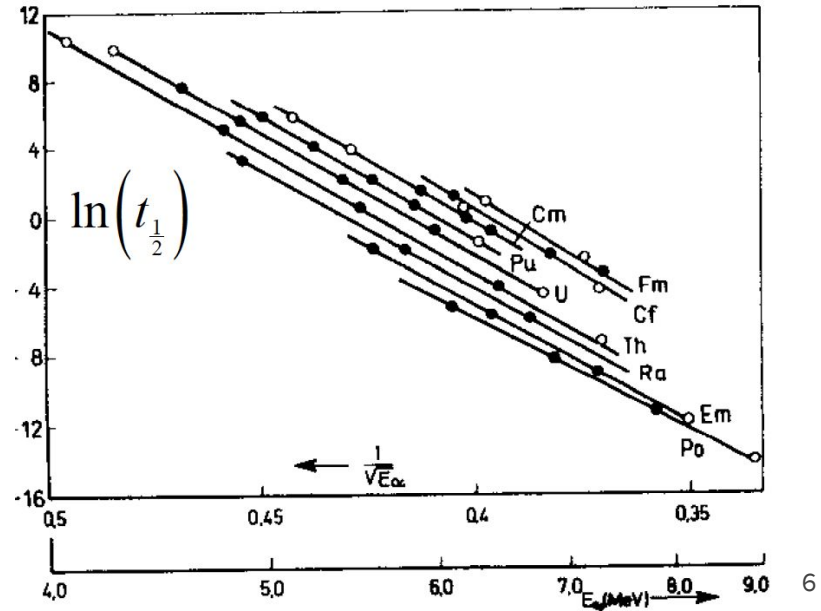
Alpha Decay

Energetics

$$Q_\alpha = B(^{A-4}_{Z-2}X'_{N-2}) + B(^4He) - B(^A_Z X_N) = B(A-4, Z-2) - B(A, Z) + B(^4He)$$
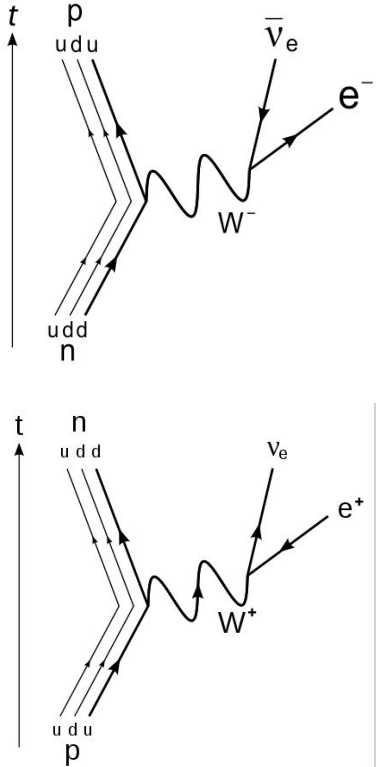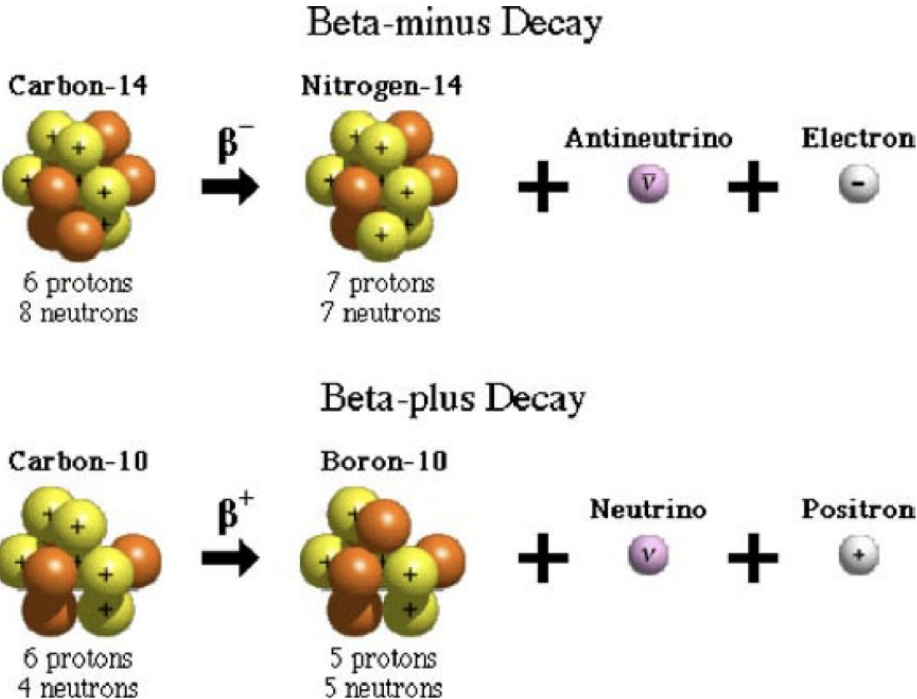
$$Q_\alpha = [B(A-4, Z-2) - B(A, Z-2)] + [B(A, Z-2) - B(A, Z)] + B(^4He) \approx = -4\frac{\partial B}{\partial A} - 2\frac{\partial B}{\partial Z} + B(^4He)$$

$$= 28.3 - 4a_v + \frac{8}{3}a_s A^{-1/3} + 4a_c \left(1 - \frac{Z}{3A}\right)\left(\frac{Z}{A^{1/3}}\right) - 4a_{sym}\left(1 - \frac{2Z}{A} + 3a_p A^{-7/4}\right)^2$$

With $Z \approx 0.41A$
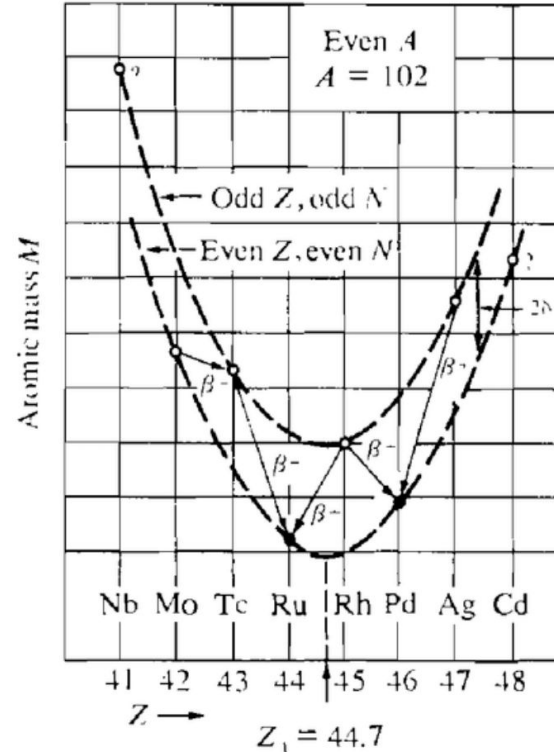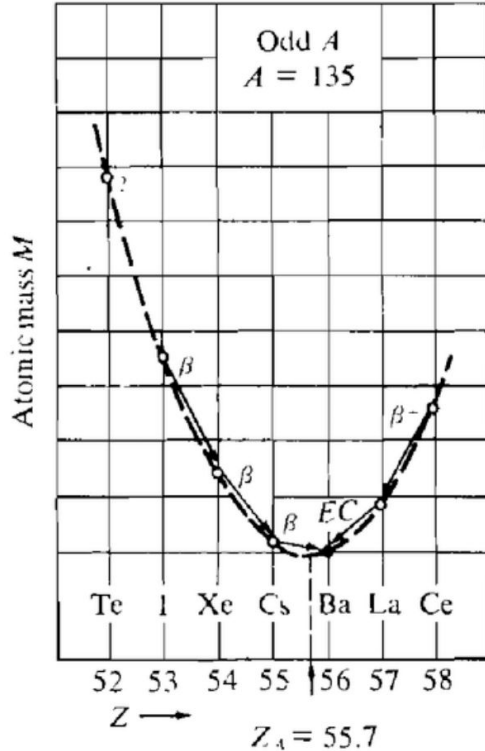
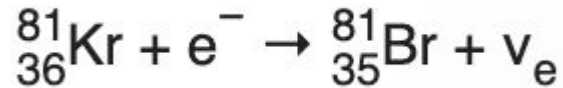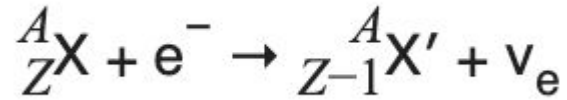$$Q_\alpha \approx -36.68 + 44.9A^{-1/3} + 1.02A^{2/3}$$

Beta Decay

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Beta-minus Decay

Carbon-14 $\xrightarrow{\beta^-}$ **Nitrogen-14** + **Antineutrino** $\bar{\nu}$ + **Electron** –

6 protons
8 neutrons

7 protons
7 neutrons

Beta-plus Decay

Carbon-10 $\xrightarrow{\beta^+}$ **Boron-10** + **Neutrino** ν + **Positron** +

6 protons
4 neutrons

5 protons
5 neutrons

Image courtesy of Thomas Jefferson National Accelerator Facility - Office of Science Education.
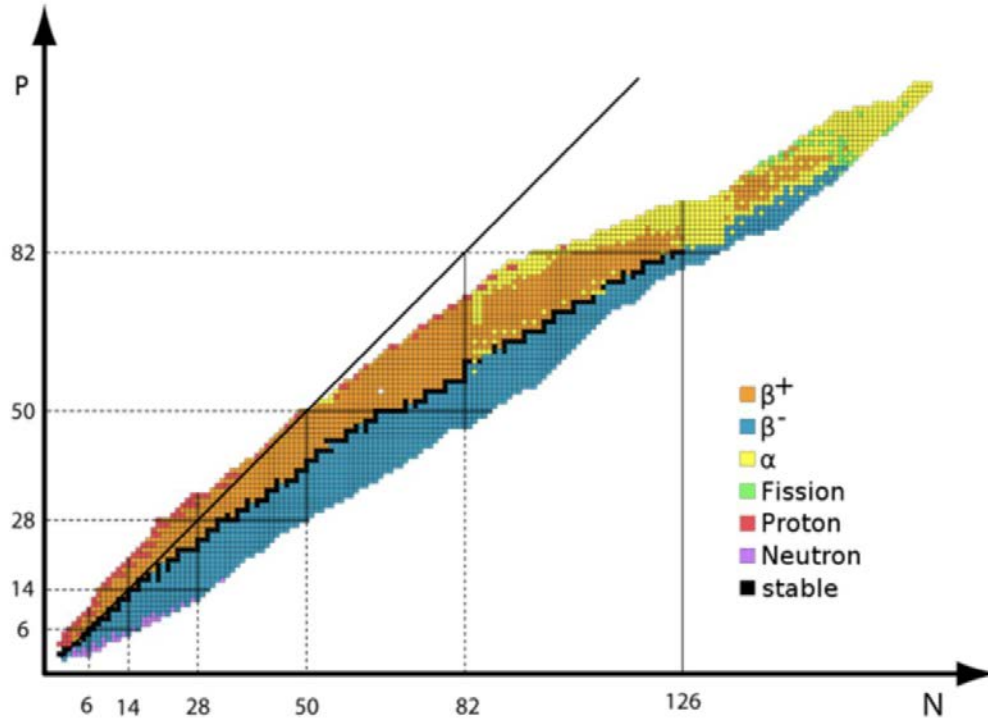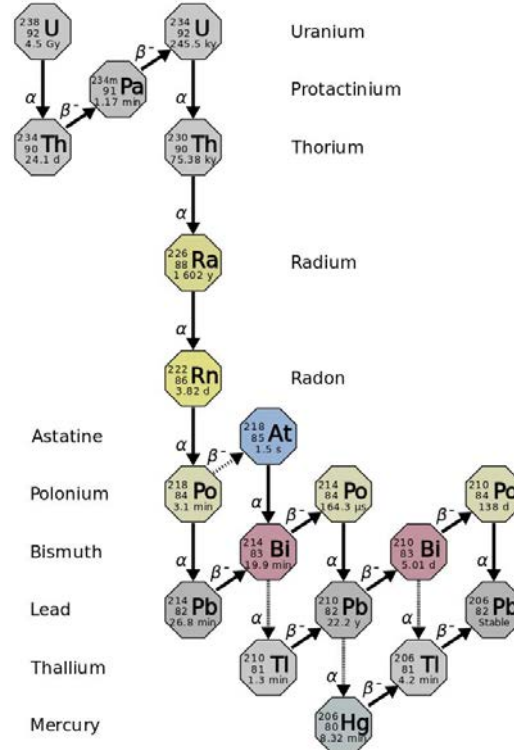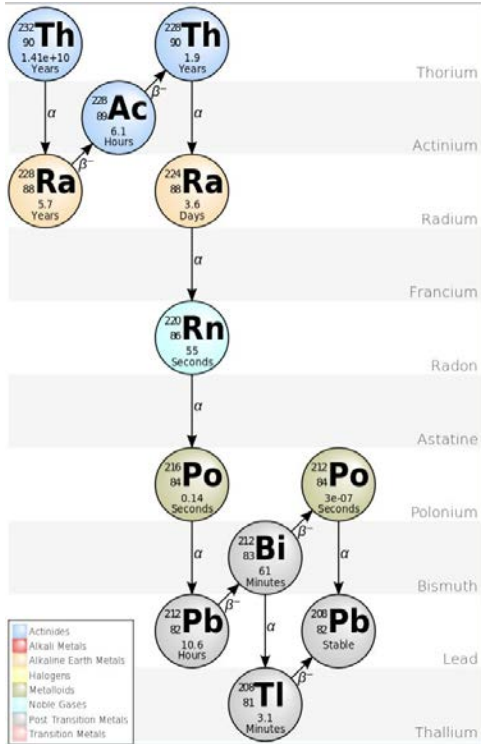
Beta Decay

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Electron Capture
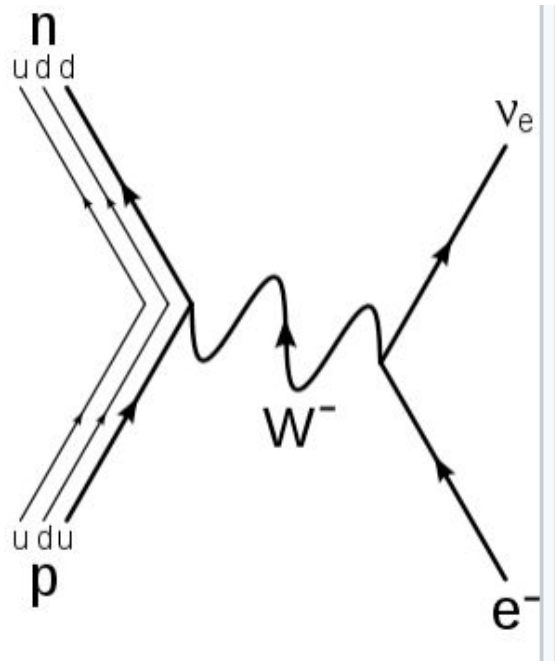
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$$\sideset{^A_Z}{}X + e^- \rightarrow \sideset{^A_{Z-1}}{}X' + \nu_e$$

$$\sideset{^{81}_{36}}{}Kr + e^- \rightarrow \sideset{^{81}_{35}}{}Br + \nu_e$$

Nuclear Decays

Long Nuclear Decay Chains

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