Lecture 13/14

Nuclear binding energies

Binding energy per nucleon maximum for ^{56}Fe: $B/A \simeq 8.8$ MeV

- nuclei with $A < 56$ can lower energy by fusion
  (powers stars, stops around ^{56}Fe)
- nuclei with $A > 56$ can lower energy by α decay or fission
  (fission: basis for nuclear reactors, occurs for $A \gtrsim 225$)

Beta-stable nuclei

- light nuclei ($A \lesssim 20$) $N \simeq Z$ (asymmetry energy)
- heavier nuclei $N > Z$ (effect of Coulomb energy)

Drip lines: unable to bind another p or n $\rightarrow$ separation energy

$$S_p = M(Z-1, A-1) + M(^1\mathrm{H}) - M(Z, A) < 0$$

or

$$S_n = M(Z, A-1) + M_n - M(Z, A) < 0$$

Beta decays

Nuclei away from line of stability decay by weak interaction

- odd A: only one stable isobar
- even A: one or two stable isobars*
- $M(Z,A) - M(Z+1,A) > 0$: ${}^A_Z X$ decays by β^-
- $M(Z,A) - M(Z-1,A) > 2m_e$: by β^+ or electron capture (EC)
- $2m_e > M(Z,A) - M(Z-1,A) > 0$: only by electron capture

$*$ $M(Z,A) - M(Z+2,A) > 0$ but $M(Z,A) - M(Z+1,A) < 0$: ${}^A_Z X$ can decay, but only by very rare double-β process

Alpha decays

${}^4_2$He nucleus (α particle) light, small Z, strongly bound $B = 28.3$ MeV
All nuclei with $A > 208$ can decay by emitting α particles
(also a few lighter nuclei can)

$$ {}^A_Z X \to {}^{A-4}_{Z-2} Y + {}^4_2\mathrm{He} $$

Rate determined by tunnelling through Coulomb barrier

- decay rate $\lambda \propto T$, tunnelling factor

$$ T = \exp\left[-\sqrt{E_G/Q}\right] $$

  Gamow energy: $E_G = 2(\pi Z_1 Z_2 \alpha)^2 M_r c^2$
  ($Z_1 = Z - 2$, $Z_2 = 2$, M_r: reduced mass)

- exponential dependence on energy release, $Q \sim 2 - 10$ MeV
  $\to$ lifetimes range over > 30 orders of magnitude