

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

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

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

Beta decays

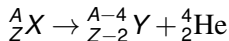
Nuclei away from line of stability decay by weak interaction

- 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

${}^4_2\text{He}$ 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)



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
→ lifetimes range over > 30 orders of magnitude