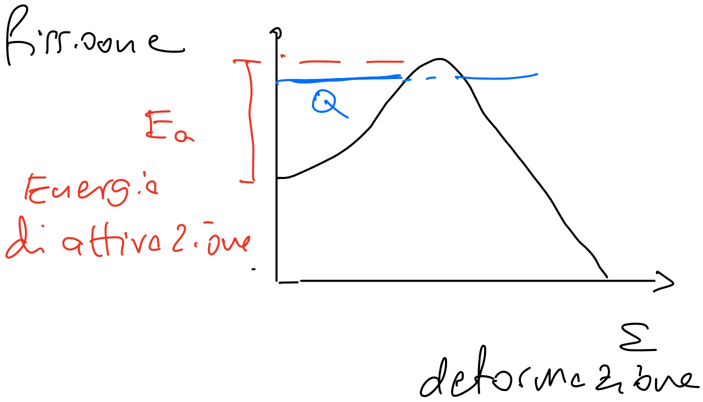
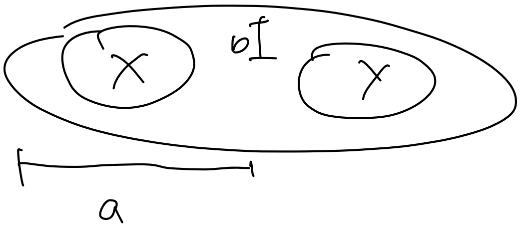
Fissione dell'uranio

$$ {}^{A}_{Z}N \longrightarrow {}^{A-a}_{Z-b}X + {}^{a}_{b}Y + Q $$

Fissione



$A \geq 200$ probabile



$a = R(1+\varepsilon)$

$Q > E_a$ fissione spontanea. $A \geq 300$

$Q \lesssim E_a$ effetto tunnel avviene fissione spontanea $A \simeq 240$

$Q < E_a \implies$ serve neutroni per fissione indotta.

$$ Q + K_n \geq E_a $$

Uranio abbondante crosta terrestre

${}^{238}_{92}U$ 99.3% $Q = 4.8$ MeV $E_a = 6.6$ MeV

${}^{235}_{92}U$ 0,7% $Q = 6.5$ MeV $E_a = 6.2$ MeV

$\langle \# n \rangle \simeq 2.5$

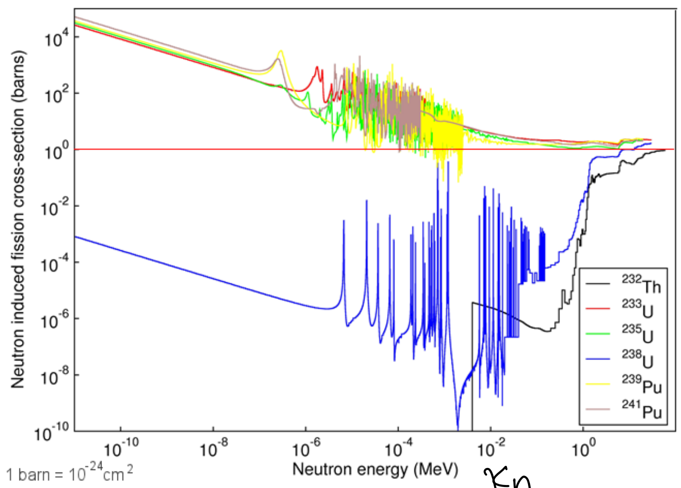
$$ n + {}^{235}_{92}U \longrightarrow \left\{ \begin{array}{l} {}^{87}_{35}Br + {}^{148}_{57}La + n \\ {}^{93}_{37}Rb + {}^{141}_{55}Cs + n + n \\ {}^{141}_{56}Ba + {}^{92}_{36}Kr + n + n + n \end{array} \right\} + Q $$

en. prodotta

$n: \; K_n \simeq \emptyset$

$T = 20\ °C$

K: Boltzmann $\implies$ $K_n \simeq 0.025$ eV



K_n energia cinetica

Fissione uranio: $\langle \# n \rangle \simeq 2.5$

$\bar{Q} \simeq 200 \text{ MeV}$

$$\eta = \frac{Q}{m} = \frac{200 \text{ MeV}}{220 \text{ GeV}} \simeq 10^{-3}$$

Nei decadimenti successivi di Rb, Kr, La, Ba, Cs

altre energie emesse E_ν, E_n,

Energia prodotta nella fissione di 1g di ^{235}U

$$Q_{tot} = \underbrace{\frac{1}{235}}_{\# \text{moli}} \times N_A \times Q = \frac{1}{235} \times 6. \times 10^{23} \times 200 \text{ MeV} \simeq 5 \times 10^{29} \text{ eV}$$

$$1 \text{ eV} = 1.6 \times 10^{-19} \text{ J}$$

$$\Rightarrow Q_{tot}^{1g\, U^{235}} = 10^{11} \text{ J}$$

$$Q_{Fissione}^{1g\, U} \simeq 3 \times Q_{Combustione}^{1\, Ton.\, Carbone}$$

Termalizzare neutroni:

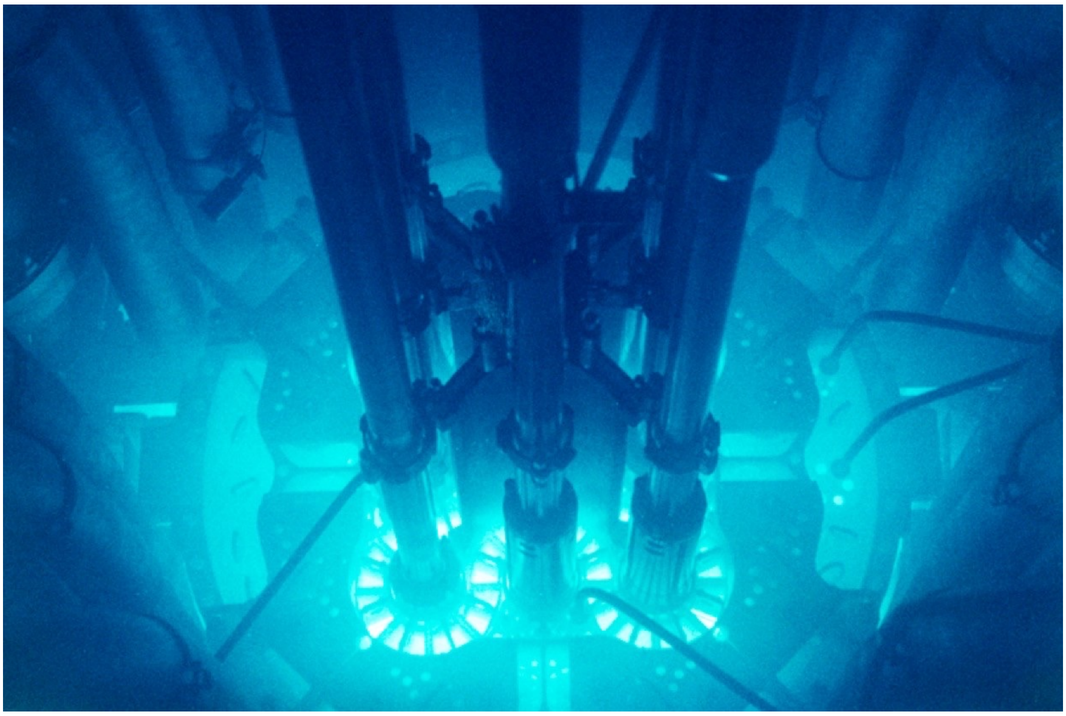
ridurre en. cinetica a temp. ambiente

$\Rightarrow$ serve mat. con $m \simeq m_n$.

$\Rightarrow$ acqua. H_2O

acqua pesante D_2O $D = {}^2_1H$

$n + D_2O \longrightarrow$ n perde en. cinetica



Luce Cerenkov dei prodotti di decadimento

Scorie nucleari

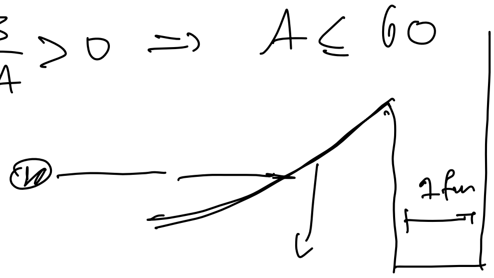
$$n + {}^2_1H = \begin{cases} \underbrace{{}^3_1H}_{\text{trizio}} \to {}^3_2He + \underbrace{e^- + \nu_e}_{18\ \text{keV}} & \text{anelastico} \quad T_{1/2} = 12\ \text{yr} \\ {}^3_1H^* \to {}^3_1H + \gamma & \text{anelastico.} \\ & \hookrightarrow \text{energetici} \sim O(\text{MeV}) \\ n + {}^2_1H & \text{elastico} \end{cases}$$

Fusione Nucleare

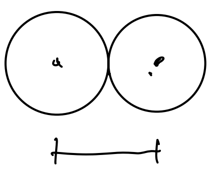
$${}^a_bX + {}^A_ZY \to {}^{A+a}_{Z+b}N + Q \qquad Q > 0 \text{ produco energia.}$$

$$Q > 0 \Rightarrow \frac{\partial B}{\partial A} > 0 \Rightarrow A \leq 60$$

$p + p$



Barriera di Coulomb del protone.



2R

$$U(2R) = \frac{e^2}{4\pi}\,\frac{1}{2R_0} = \frac{\alpha}{2}\,\frac{1}{r_0}\,\frac{1}{A^{1/3}} \simeq 550\ \text{keV}$$

En. cin. necessaria per interazione nucleare p+p : 550 KeV

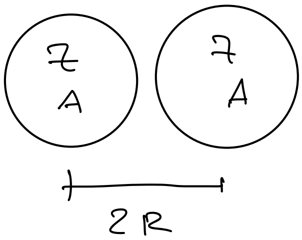
Fusione nuclei di massa M.

$$M + M \to X + Q.$$

M: massa nucleo iniziale

Q: en. prodotta.

$$\text{rendimento } \eta = \frac{Q}{2M}$$



$$U(2R) = \frac{e^2}{4\pi}\frac{Z^2}{2R} = \frac{\alpha}{2}\frac{Z^2}{r_0 A^{1/3}}$$

$$r_0 \simeq 1.1 \text{ fm} \simeq (200 \text{ MeV})^{-1}$$

$$\alpha = 1/137$$

$Z \simeq \frac{A}{2}$ A piccoli

$$U(2R) \simeq \frac{\alpha}{2}\frac{A^2}{4}\frac{1}{r_0 A^{1/3}} \simeq (0.145 \text{ MeV}) A^{5/3}$$

Helio: $A=4,\ Z=2$ $\quad U(2R) \simeq 1.45$ MeV

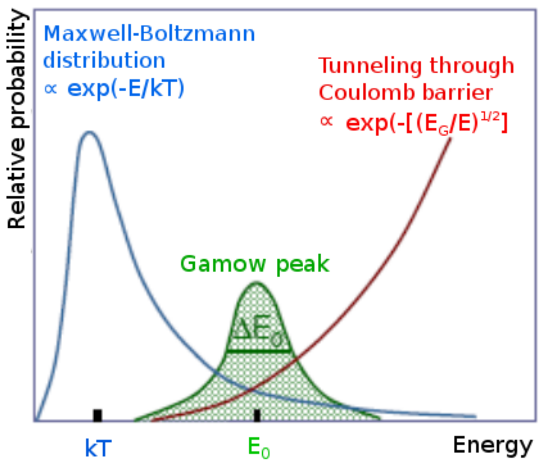
$$\bar{E} = 1.45 \text{ MeV} = KT \qquad K = 8.6\times 10^{-5} \text{ eV}/K$$

$$\Rightarrow T = 1.6\times 10^{9} \text{ K}$$

$$\bar{E} = \frac{3}{2}KT = \frac{1}{2}m\bar{v}^2 \qquad \bar{v} = \sqrt{3\frac{KT}{m}}$$

$$\frac{dn}{dv} = \frac{v^2}{(2KT/m)^{3/2}}\, e^{-\frac{1}{2}\frac{mv^2}{KT}}$$

Distribuzione di Maxwell-Boltzmann.



Grazie a effetto tunnel alcuni nuclei possono fare fusione pur avendo

$$T < U(2R)$$

$\bar{E} < U(2R)$ ma alcune particelle $E > U(2R)$

Fusione Stellare

meccanismo principale $\quad p+p+p+p \longrightarrow He + \underbrace{26\ MeV}_{Q}$

$$\eta = \frac{Q}{M} = \frac{26\ MeV}{3700\ MeV} \simeq 7 \times 10^{-3}$$