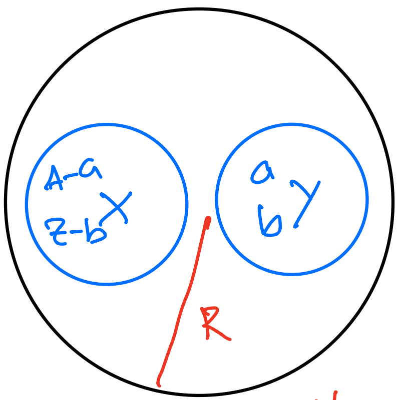
# Fissione nucleare

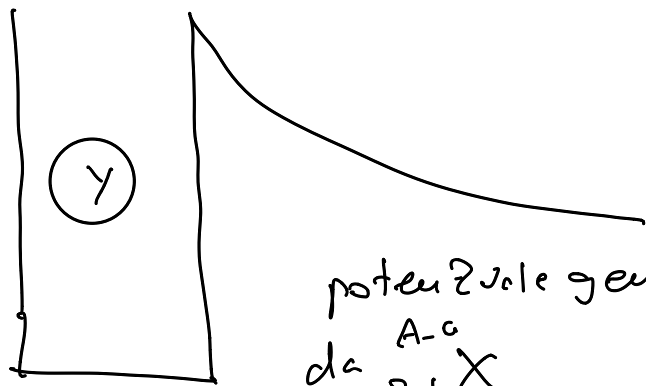
$$^{A}_{Z}N \longrightarrow \,^{A-a}_{Z-b}X + \,^{a}_{b}Y + Q$$ spontanea

$$n + \,^{A}_{Z}N \longrightarrow X + Y + Q$$ indotta.

↳ usando l'energia dei neutroni per far tornare il conto/equilibrio energetico.

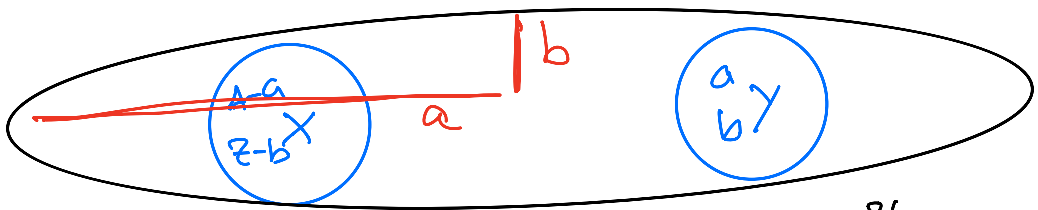



$R = r_0 A^{1/3}$




potenziale generato da $^{A-a}_{Z-b}X$

$^{a}_{b}Y$ nella buca di potenziale.




$$B(Z,A) = a_V A - a_S A^{2/3} - a_C Z^2 A^{-1/3}$$

**sfera.**

$$V = \frac{4\pi}{3} R^3$$

$$S = 4\pi R^2$$

**ellissoide**

$$V = \frac{4\pi}{3} a b b = \frac{4\pi}{3} a b^2$$

$$S \simeq 4\pi \left( \frac{a^p b^p + a^p c^p + b^p c^p}{3} \right)^{1/p}$$

$c = b \qquad p \simeq 1.6$

Relazione tra R, a, b

$a = R(1+\varepsilon)$

$$\frac{4\pi}{3} R^3 = \frac{4\pi}{3} a b^2 = \frac{4\pi}{3} R(1+\varepsilon) b^2$$

volume invariato.

$$b = \frac{R}{(1+\varepsilon)^{1/2}}$$

S' di ellissoide rispetto a S (sfera).

$\Delta$superficie $\sim \varepsilon^2$

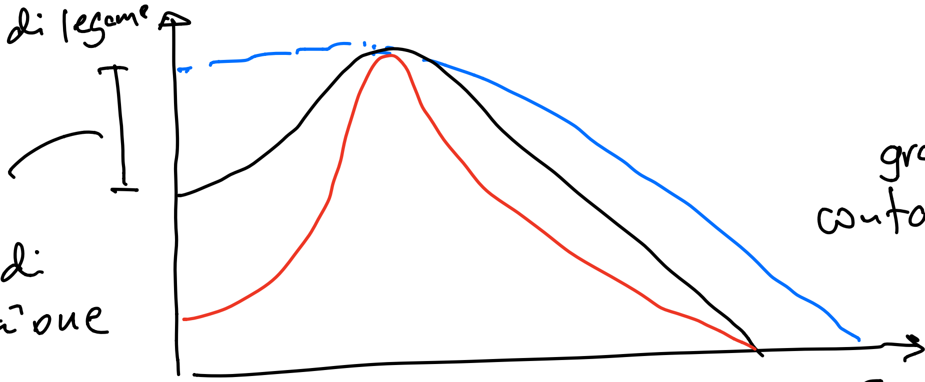
$$\Delta B \simeq -a_S A^{2/3}\left(\frac{2}{5}\varepsilon^2\right) - a_C Z^2 A^{-1/3}\left(-\frac{1}{5}\varepsilon^2\right)$$

$a_S \simeq 18$ MeV

$a_C \simeq 0.7$ MeV

B: en. di legame

Ea energia di attivazione



grafici non in scala. conta solo l'andamento

$\varepsilon$ deformazione.

energia di legame varia con $\varepsilon$ in maniera diversa in base a A, Z

Fissione favorita per $\Delta B \simeq 0$

$$\Delta B = 0 \Rightarrow a_S A^{2/3} \frac{2}{5}\varepsilon^2 = a_C Z^2 A^{-1/3} \frac{1}{5}\varepsilon^2$$

$$2\frac{a_S}{a_C} A = Z^2$$

$$\simeq \frac{2 \times 18}{0.7} \simeq 50 \Rightarrow \frac{Z^2}{A} \simeq 50$$

$$A \simeq 2Z \Rightarrow \frac{A^2}{4}\frac{1}{A} \simeq 50 \Rightarrow A \simeq 200$$

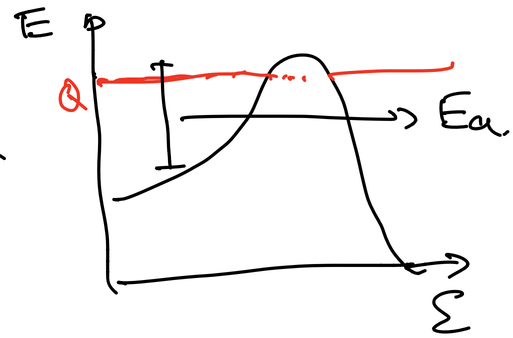
studiando Bethe-Weizsäcker

$A \simeq 300 \qquad Q > E_a$

$A \simeq 240 \qquad E_a - Q \simeq 6$ MeV

$Q < E_a$

Effetto tunnel aiuta/aumenta prob. di fissione spontanea.




$A \simeq 100 \qquad E_a - Q \simeq 60$ MeV

fissione spontanea improbabile.

Fissione dell'uranio

abbondanze naturale.

${}^{238}_{92}U \quad 99.3\%$ $\qquad {}^{235}_{92}U \quad 0.7\%$

${}^{235}_{92}U$

$$n + {}^{235}_{92}U \longrightarrow {}^{236}_{92}U^*$$

$$Q = M({}^{235}U) + m_n - M({}^{236}U) = 6.5 \text{ MeV.}$$

${}^{235}U$ : $\quad E_a = 6.2$ MeV

$$\sigma(n + {}^{235}U \rightarrow 236) = 580 \text{ b}$$

$T \simeq 20^\circ C \qquad K_n \simeq 0.025$ eV

${}^{238}U$

$$n + {}^{238}_{92}U \longrightarrow {}^{239}_{92}U$$

$Q = 4.8$ MeV $\qquad E_a = 6.6$ MeV.

$Q < E_a$.

$E_a - Q = 1.8$ MeV

$$n + {}^{235}_{92}U \longrightarrow \begin{cases} {}^{87}_{35}Br + {}^{148}_{57}La + n \\ \\ {}^{93}_{37}Rb + {}^{141}_{55}Cs + n + n \\ \\ {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3n \end{cases}$$

$\bar{Q} \simeq 200$ MeV per nucleo.

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

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

Nei decadimenti $\beta$ successivi

$$E_\nu \simeq 12 \text{ MeV}$$

$$E_n \simeq 2 \text{ MeV}$$

$$E_{\substack{nuc \\ ecc.}} \simeq 8 \text{ MeV}.$$

1 g di uranio.

$$Q = \underbrace{\frac{1}{235}}_{\#\text{ moli}} \times \underbrace{6.\times 10^{23}}_{NA} \times \underbrace{200 \text{ MeV.}}_{Q \text{ per nucleo.}} = 5\times 10^{29} \text{ eV.}$$

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

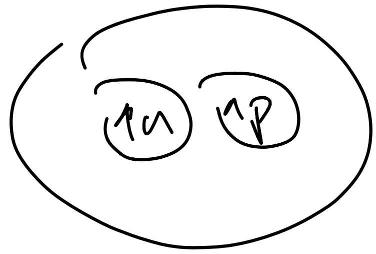
$$Q \simeq 5\times 10^{29} \times 1.6 \times 10^{-19} \simeq 10^{11} \text{ J}$$

$Q \simeq 3\times$ energia di combustione di 1T C termalizzazione di neutroni

per far perdere en. cin. ai neutroni: urti contro protoni
neutroni

acqua $H_2O$

acqua pesante $D_2O$

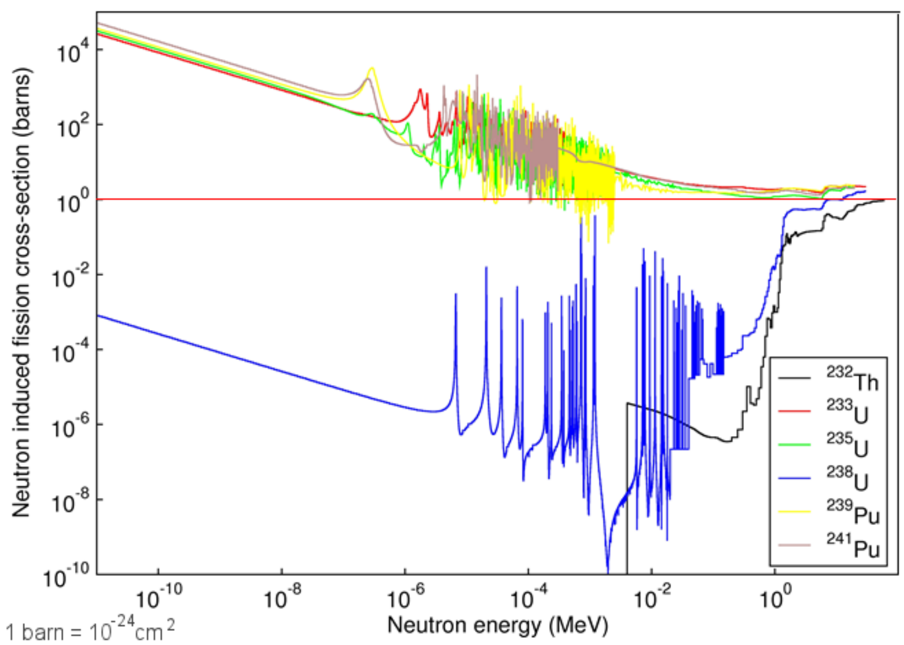



produco 2.5 neutroni nella fissione.

$\Rightarrow$ urto contro $D_2O$

$\Rightarrow$ ottengo neutroni bassa energia.

$\Rightarrow$ far ripartire catene fissione




sezione d'urto di $n+X$ diminuisce con $K_n$

## Scorie nucleari

$$\alpha + {}^2_1H \rightarrow {}^3_1H + \underbrace{e^- + \nu_e}_{18\,keV}$$

trizio $\qquad \tau_{1/2} \simeq 12\ yr$

$$n + {}^2_1H \rightarrow {}^3_1H^* \rightarrow {}^3_1H + \gamma$$

fotoni energetici

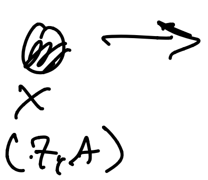
$$n + {}^2_1H_1 \begin{cases} \text{elastico - termalizzazione} \\ \text{anelastico} \quad {}^3_1H \\ \text{anelastico} \quad {}^3_1H^* \end{cases}$$

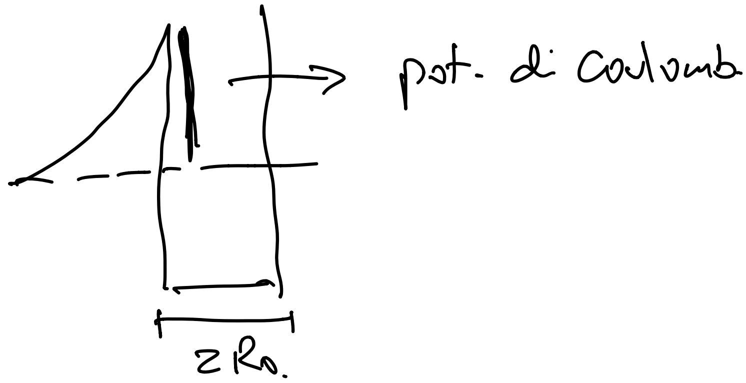
$$N_{eventi} = (\sigma_{el} + \sigma_{an.} + \sigma^*_{an}) \cdot n \cdot d$$

## Fusione nucleare

$${}^a_bX + {}^A_ZY \rightarrow {}^{A+a}_{Z+b}N + Q$$

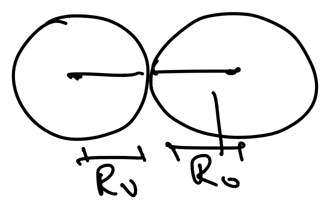
$$Q > 0 \text{ se } \frac{\partial \bar{B}}{\partial A} > 0 \Rightarrow A \lesssim 60$$




$$U(2R_0) = \frac{e^2}{4\pi} \frac{1}{2R_0}$$

$$= \frac{\alpha}{2} \frac{1}{r_0} \frac{1}{A^{1/3}}$$



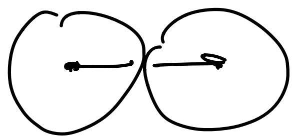
$= \frac{1}{137} \frac{1}{2} \frac{1}{1.1\ \text{fm}}$ $\qquad 1 = 200\ \text{MeV} \times \text{fm}.$

$U(2R_0) \simeq 550\ \text{KeV}$

$p + p \longrightarrow$

$E_{min.}$ per fusione $\simeq 550$ KeV.

$^{12}_{6}C$



$^{12}_{6}C + ^{12}_{6}C \longrightarrow ^{24}_{12}Mg$ $\qquad Q = 13\ \text{MeV}.$

$U(2R) \simeq 9\ \text{MeV}.$

$M_C = 6m_p + 6m_n - 12 \times \underbrace{7.5}_{\bar{B}}\ \text{MeV} \simeq 11.2\ \text{GeV}$

$\eta = \frac{Q - 9\ \text{MeV}}{2 M_C} \simeq 2 \times 10^{-4}$