

$$B(Z, A) = \alpha_V A +$$

- $\alpha_S A^{2/3} +$
- $\alpha_C Z^2 A^{-1/3} +$
- $\alpha_F \frac{(A - Z)^2}{A} +$

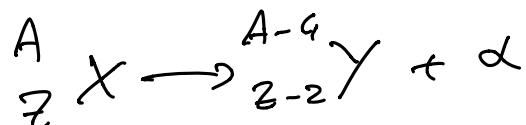
$$\pm \delta$$

Decadimento α

- tipicamente avviene per $A > 200$

- $K_\alpha \approx 4-8 \text{ MeV}$ $K_\alpha = 5 \text{ MeV}$

- decadimento a 2 corpi:



- tempo di dimezzamento $T_{1/2}$ funzione forte di K_α

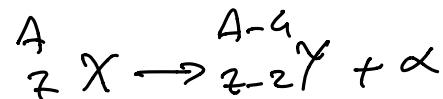
$$\ln T_{1/2} = a - b \ln K_\alpha \quad \text{Legge di Geiger - Nuttal}$$

$K_\alpha \rightarrow \infty \text{ MeV}$ $T_{1/2}$ varia di ordini di grandezza

Cinematico decadimento:
nel c.d.m di X

$$M_X = M_Y + M_\alpha + K_\alpha + K_Y$$

$$\vec{P}_\alpha + \vec{P}_Y = \emptyset$$



$$P_Y = P_\alpha = P$$

$$Q = M_X - M_Y - M_\alpha = K_\alpha + K_Y = \frac{P^2}{2m_\alpha} + \frac{P^2}{2m_Y}$$

$$= \left(\frac{P^2}{2m_\alpha} \right) \left(1 + \frac{m_\alpha}{m_Y} \right)$$

$$M_Y \gg M_X \quad K_\alpha = \frac{P_E}{\text{area}} = \frac{Q}{1 + \frac{M_\alpha}{M_Y}}$$

$$\approx Q \left(1 - \frac{M_\alpha}{M_Y}\right) \approx Q \left(1 - \frac{4}{A}\right)$$

$$= (M_X - M_Y - M_\alpha) \left(1 - \frac{4}{A}\right)$$

$$K_Y = Q - K_\alpha = Q \frac{4}{A}$$

Se $A \gg 4$ $K_Y \ll K_\alpha$. K_Y ques: fra scambi

Effetto di Segrile $Q > 0$ per avere decadimento

Energia di legame gioca ruolo importante per α :

$$Q = M_X - M_Y - M_\alpha. \quad \text{Se } B = \emptyset$$

$$\infty \quad \text{s: conserva la massa, } \neq \text{nucleoni;}$$

$$Q = -B_X(A, Z) + B_Y(A-4, Z-2) + B_\alpha(4, 2)$$

$$Q_\alpha > 0 \Rightarrow B_X(A, Z) < B_Y(A-4, Z-2) + B_\alpha$$

$$\approx 28 \text{ MeV}$$

$$\frac{\partial B}{\partial A} < 0 \text{ per } A > 60$$

Se ignoro B_α . \Rightarrow decad. α avviene già per $A > 60$.

Invece sperimentalmente $A \gtrsim 200$

$$A \approx 140 \quad Q \approx 0 \quad T \rightarrow \infty \quad \ln \bar{T} = a - b \ln K_\alpha.$$

$$A \approx 200 \quad Q \approx 4 \text{ MeV}$$

$$A \approx 240 \quad Q \approx 8 \text{ MeV}$$

Se $0 < Q < 4 \text{ MeV}$ è possibile un T_{Y_2} troppo basso.

Decadimento α si comincia a vedere per $A \approx 209$
Bismuto

Tempo di riferimento $\tau_{SS} = 5 \times 10^9$ yrs
 sistema Solare

nuclide $\tau_{Y2} < \tau_{SS}$ già decaduti

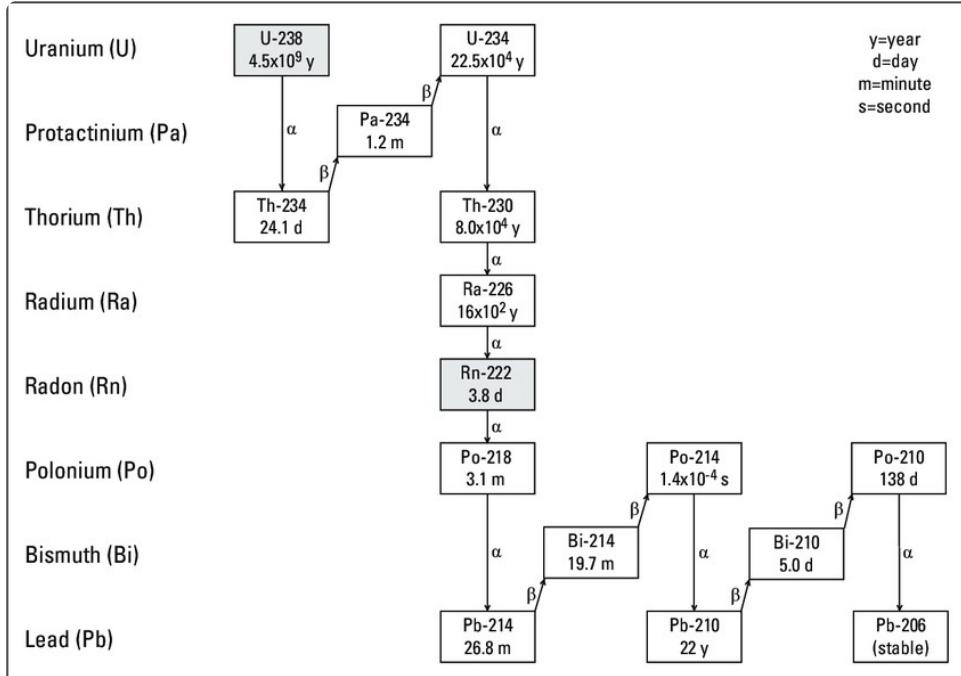
$\tau_{II_2} > \tau_{SS}$ nuclei stabili

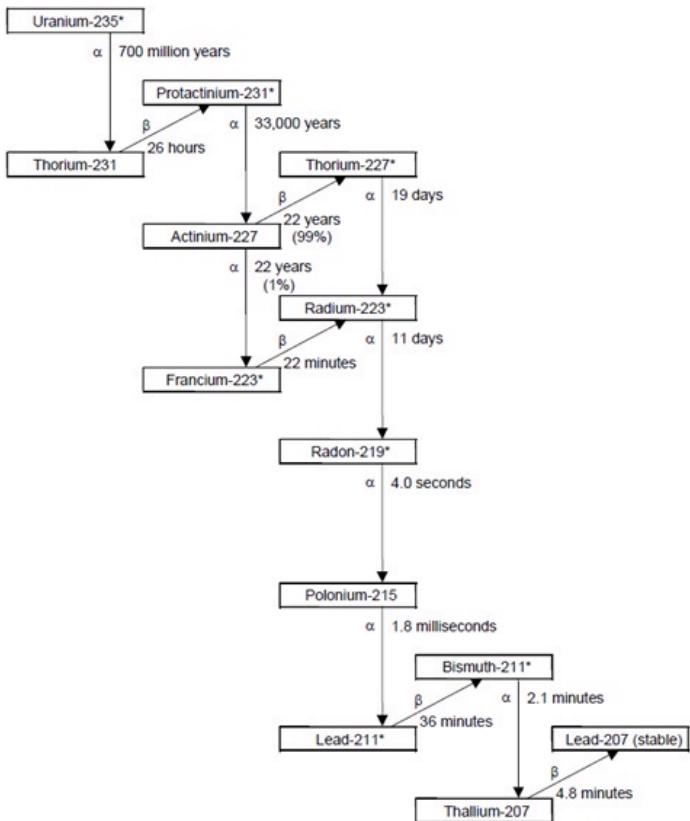
nuclidi instabili già decaduti.

$^{238}_{92}\text{U}$ (4.5×10^9 yr) $^{235}_{92}\text{U}$ (7.1×10^8 yr) $^{232}_{90}\text{Th}$ (1.6×10^{10} yr)

instabili ma ancora presenti.

\Rightarrow nelle loro catene di decadimento vengono generati altri nuclidi pesanti



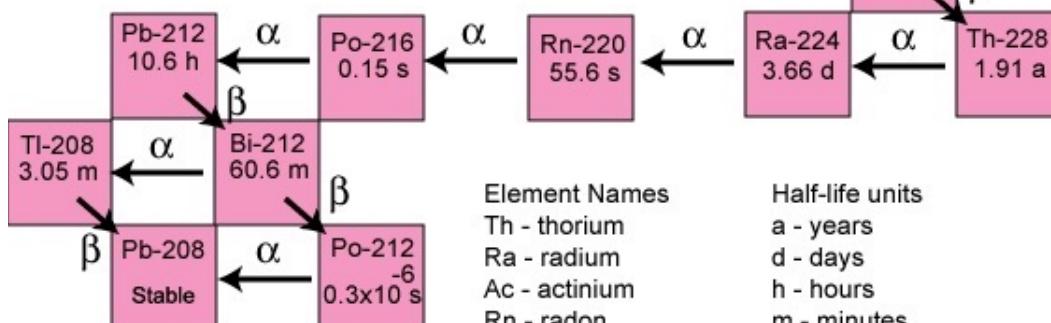


The Thorium-232 Decay Chain

Atomic Number

81 82 83 84 85 86 87 88 89 90

Only main decays are shown
Gamma emitters are not indicated

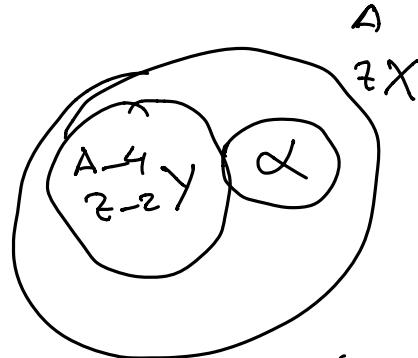
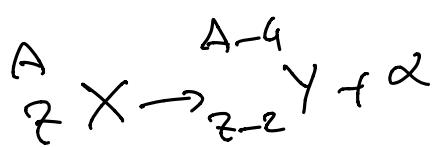


Element Names
 Th - thorium
 Ra - radium
 Ac - actinium
 Rn - radon
 Po - polonium
 Bi - bismuth
 Pb - lead
 Tl - thallium

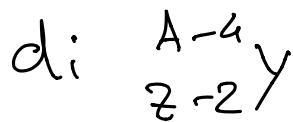
Half-life units
 a - years
 d - days
 h - hours
 m - minutes
 s - seconds

Modello di Gamow per decadimento α

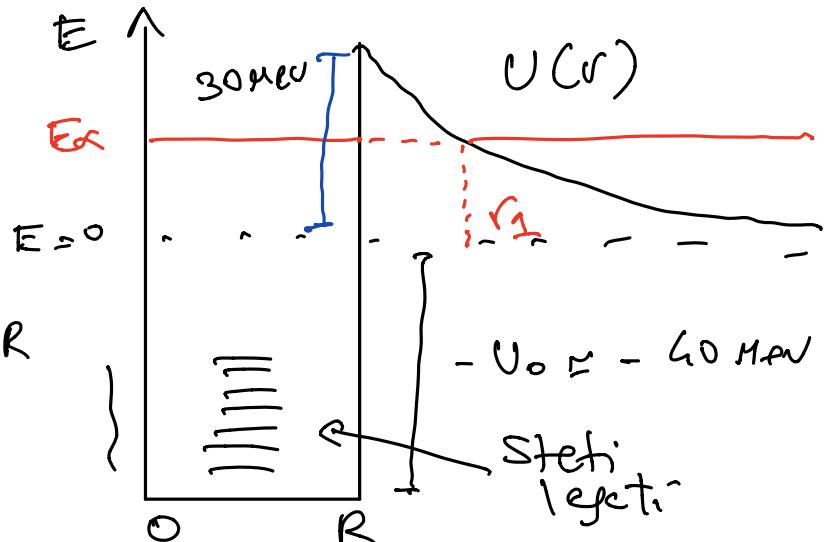
- α stato molto legato $B=28$ MeV
- nucleo pesante



particelle α intreppolate nelle bule di potenz.



$$u(r) = \begin{cases} -U_0 & r < R \\ \frac{e(z-z') e^2}{4\pi} \frac{1}{r} = \frac{\alpha e(z-z')}{r} & r > R \end{cases}$$



$$E_\alpha \approx 4-8 \text{ MeV} > 0$$

$$R = R_0 A^{1/3}$$

$$A = 200 \quad R \approx 7 \text{ fm}$$

$$U(R) = \frac{e(z-z')}{R} \alpha \approx 30 \text{ MeV}$$

$$U(r_1) = \frac{e(z-z')}{r_1} \alpha = \frac{e(z-z')}{R} \frac{R}{r_1} \alpha$$

$$\rightarrow E_\alpha$$

$$E_\alpha = \frac{e(z-z')}{R} \frac{R}{r_1} \alpha = U(R) \frac{R}{r_1}$$

$$r_1 = \frac{U(R)}{E_\alpha} R = \frac{30 \text{ MeV}}{8 \text{ MeV}} R \approx 37.5 \text{ fm}$$

$$R = 7 \text{ fm} \rightarrow r_1 = 50 \text{ fm}$$

grazie all'effetto Tunnel

E_{α} piccoli \rightarrow prob. piccole \rightarrow T grande.

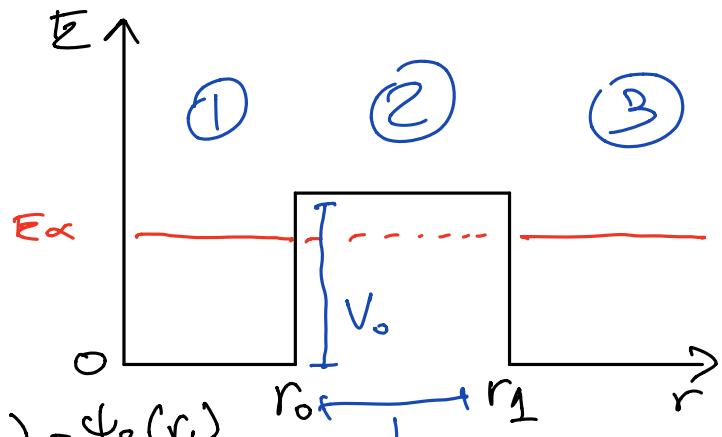
E_{α} grandi \rightarrow prob. funnel \rightarrow T piccolo
più grande

Origine di Geiger - Nuttal

Effetto funnel con barriera finita

$$\begin{cases} \psi_1 = A e^{ipr} + B e^{-ipr} \\ \psi_2 = C e^{ipr} + D e^{-ipr} \\ \psi_3 = E e^{+ipr} \end{cases}$$

$$\begin{cases} \psi_1(r_0) = \psi_2(r_0) \\ \psi'_1(r_0) = \psi'_2(r_0) \end{cases} \quad \begin{cases} \psi_2(r_1) = \psi_3(r_1) \\ \psi'_2(r_1) = \psi'_3(r_1) \end{cases}$$



$$\textcircled{1}, \textcircled{3} \quad E = \frac{p^2}{2m} \Rightarrow p_1 = \sqrt{2mE}$$

$$p_1 \approx p_3$$

$$\textcircled{2} \quad E_2 = V_0 - \frac{p_2^2}{2m} \Rightarrow p_2 = \sqrt{2(V_0 - E)m}$$

$$\text{Coeff. di Trasmissione: } T = \frac{|E|^2}{|A|^2}$$

$$T = \frac{V_0^2}{1 + \frac{V_0^2}{(2E - V_0)^2} \sinh^2(\frac{p_2 L}{m})}$$

$$X \equiv p_2 L \quad L \approx 10 \text{ fm}$$

$$P_2 = \sqrt{2m(V_0 - E_x)}$$

$$V_0 \approx 30 \text{ MeV} \quad E_x = 5 \text{ MeV}$$

$$m_e = 3700 \text{ MeV}$$

$$P_2 \approx 430 \text{ MeV}$$

$$x = P_2 L = 80$$

$$\sinh^2 x = \left(\frac{1}{2} (e^{-x} - e^x) \right)^2 = \frac{1}{4} (e^{-2x} + e^{2x}) - \frac{1}{2}$$

$$x = 80 \Rightarrow e^{-80} \approx 0 \quad e^{80} \gg \frac{1}{2}$$

$$\sinh^2 x \approx \frac{1}{4} e^{2x} \gg 1$$

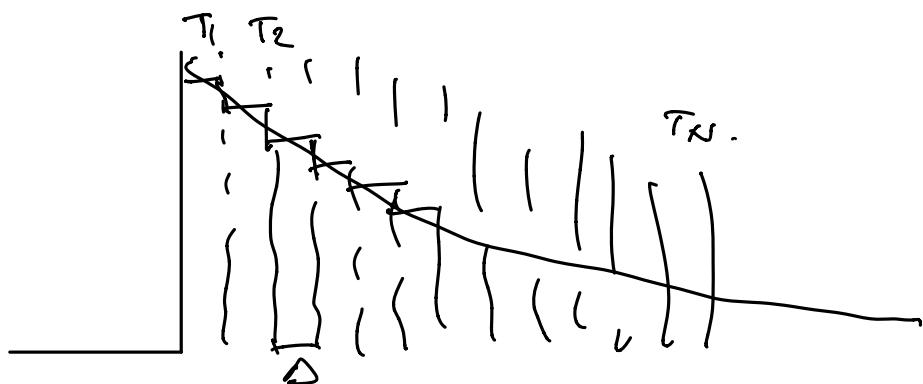
$$T = \frac{\frac{1}{4} e^{2P_2 L}}{\frac{V_0^2}{V_0^2 - (E - V_0)^2}} = G \frac{V_0^2 - (E - V_0)^2}{V_0^2} e^{-2P_2 L}$$

V_0, E in funzione di P_1 e P_2

$$T = 16 \frac{P_1^2 P_2^2}{(P_1^2 + P_2^2)^2} e^{-2P_2 L} = A e^{-2P_2 L}$$

$$T = A e^{-2G}$$

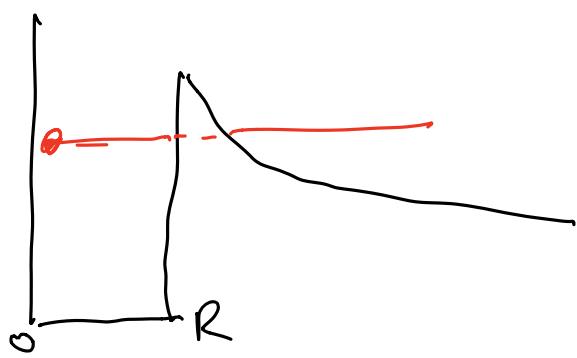
Fattore di Gauss



$$T = A \cdot T_1 \cdots T_N$$

$$G = \int_{r_0}^{\infty} dr \sqrt{2m(V_0 - E)}$$

$$T = A e^{-2G}$$



$$\lambda = T \cdot f$$

freq. di urto contro
barriera

prob. per urto di term.
di superare la barriera

$$f = \frac{1}{\Delta T} = 2 \frac{v}{R}$$

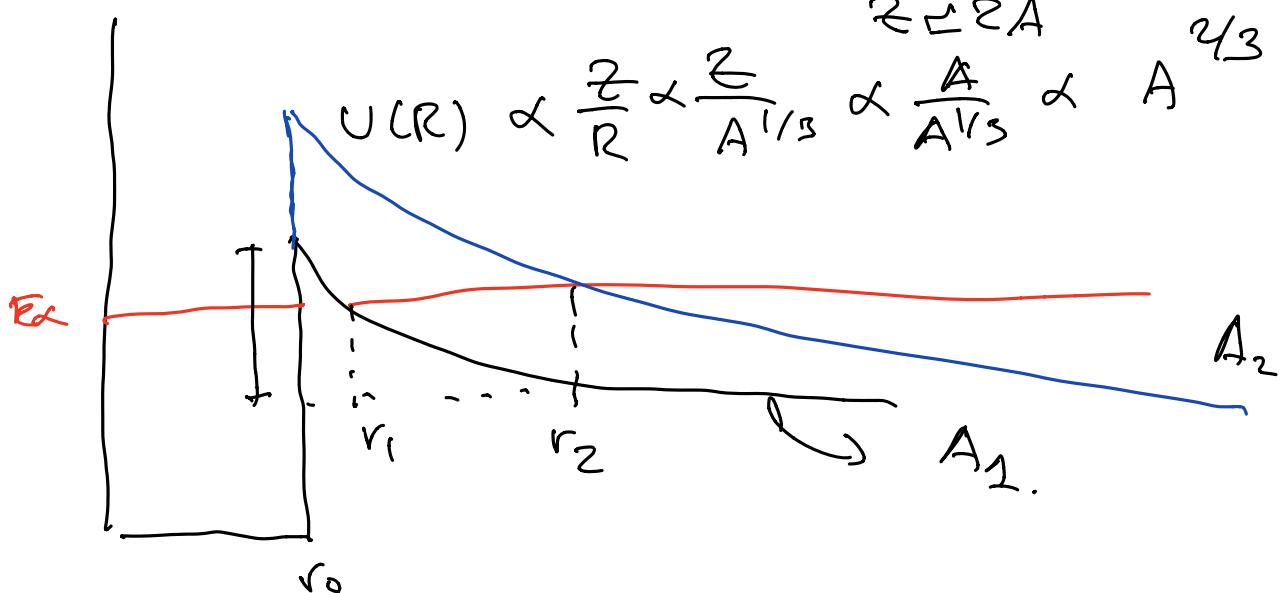
$$= 2 \sqrt{\frac{eE}{m}} \frac{1}{R} \Rightarrow \lambda = 2 \sqrt{\frac{eE}{m}} \frac{1}{R} e^{-2G}$$

$$\lambda = \frac{1}{T} \rightarrow T \propto E^{-1/2} e^{2G}$$

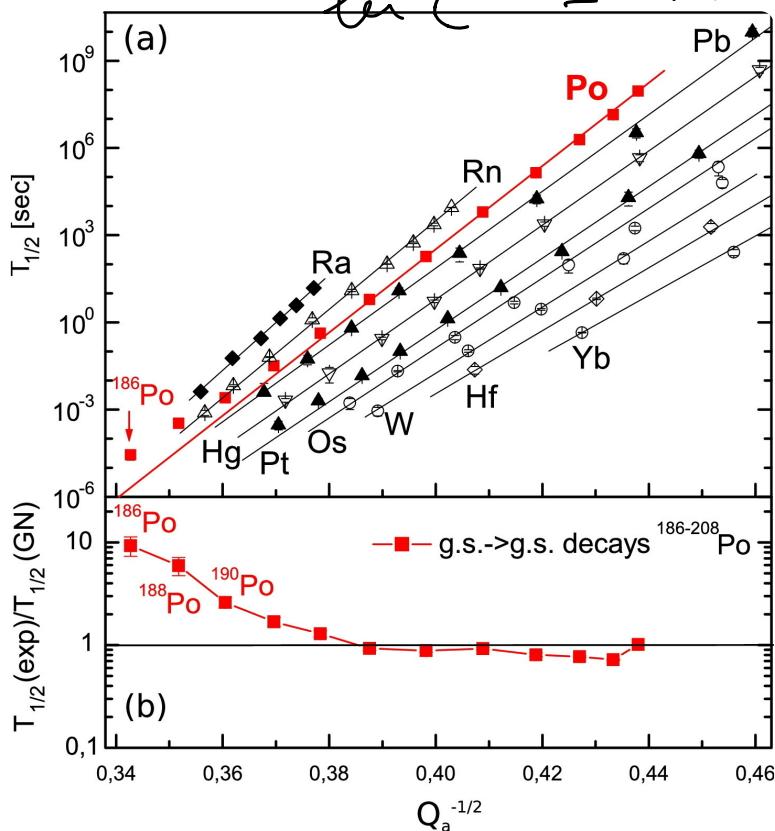
$$\ln T = A - B \ln \sqrt{E_x}$$

Lesse di Geiger
Nuttall

G dipende da E_x
ma debole



Per E_x fisso: $T_2 > T_1$



$$\ln \tau = A - B \ln \sqrt{E_\alpha}$$

$$A + B \ln \frac{1}{\sqrt{E_\alpha}}$$

$$\frac{1}{Q^{1/2}} = \frac{1}{\sqrt{E_\alpha}}$$

misura
Calcolo GN

Radioattività e unità di misura

Dato un materiale ci sono 2 utili:

1/ # decadimenti / s

2/ effetti prodotti nei tessuti biologici

α, β, γ

δ, e^-, e^+ , γ

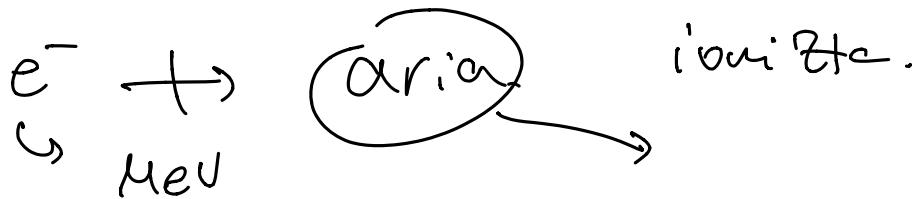
spettro energetico diverso

decadimenti a prescindere dall'energia

1 Bq (Bequerel) = 1 dec./sec.

$$1 \text{ Ci (curie)} = 3.7 \times 10^{10} \text{ dec/sec.}$$

Energia dei prodotti radioattivi:



Ionizz del mezzo attraversato dai prodotti:

$$1 \text{ R (Röntgen)} = 2.58 \times 10^{-4} \text{ C/kg}$$

aria @ 20°C
1 A

Conice generale per
ioniizzazione

radiation absorbed dose = rad

$$1 \text{ rad} = 10^{-2} \text{ J/kg} = 10^{-2} \text{ Gy (Gray)}$$

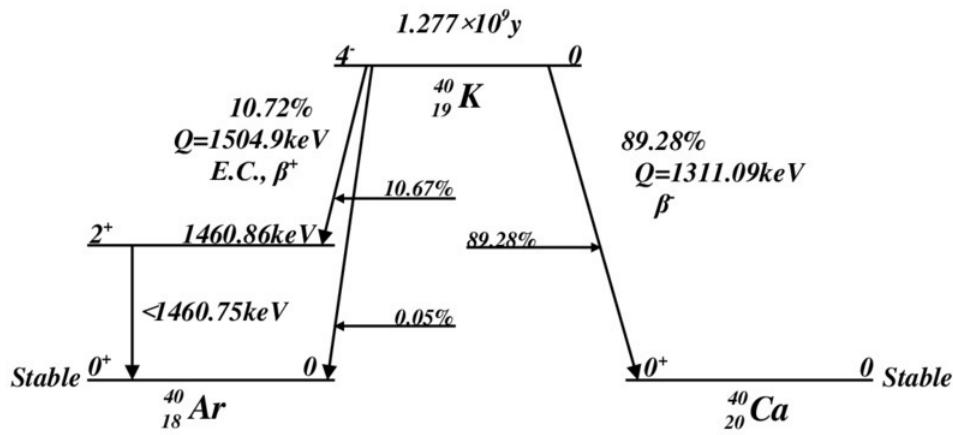
α , β , e^- , γ interazioni dirette nel
mezzo.

$$1 \text{ Sv (Sievert)} = w_R \times (\text{dose in Gy})$$

↙
Fattore di pericolosità

Radiation type and energy	Radiation weighting factor, w_R
Photons, all energies	1
Electrons, muons, all energies	1
Neutrons below 10 keV	5
from 10 keV to 100 keV	10
from 100 keV to 2 MeV	20
from 2 MeV to 20 MeV	10
over 20 MeV	5
Protons over 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

Banane ricche di ^{40}K



Dose equiv. per una banana è 10^{-7} Sv

- non accumuliamo ^{40}K

- 1 banana dà dose equiv.

$\sim 1\%$ radioattività naturale
sulla terra in 1 giorno.

In un anno radioattività naturale

$\approx 3 \text{ mSv}$

lastra petto 0.1 mSv

dosimetro
del Cervello 2 mSv