

# Energia di legame nucleare

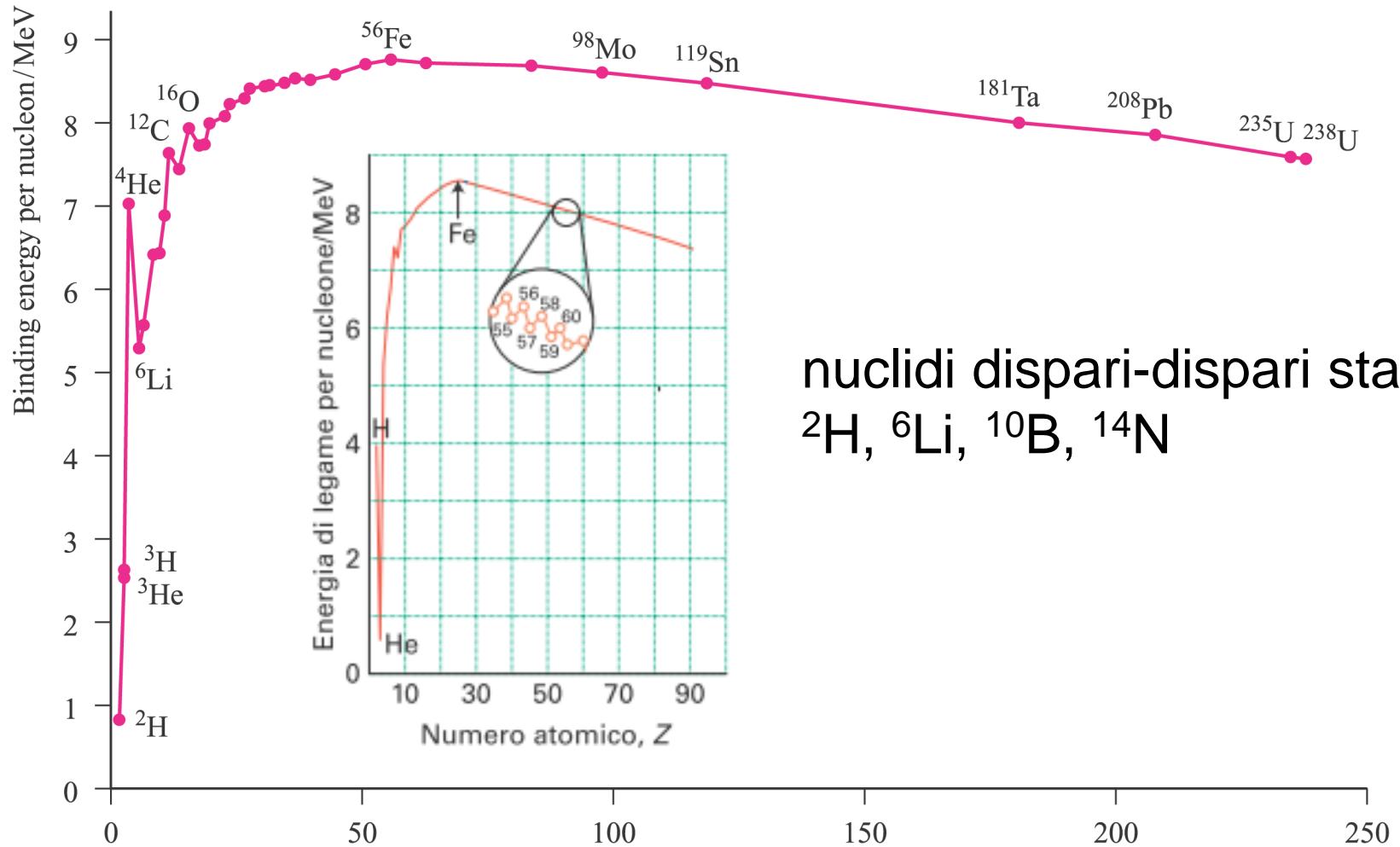
$$\Delta E = \Delta mc^2$$

$$c = 2.998 \times 10^8 \text{ m s}^{-1}$$

1 mole  ${}^7\text{Li}$ :  $3.79 \times 10^9 \text{ kJ}$

*1 mole butano: 2857 kJ*

# Energia per nucleone



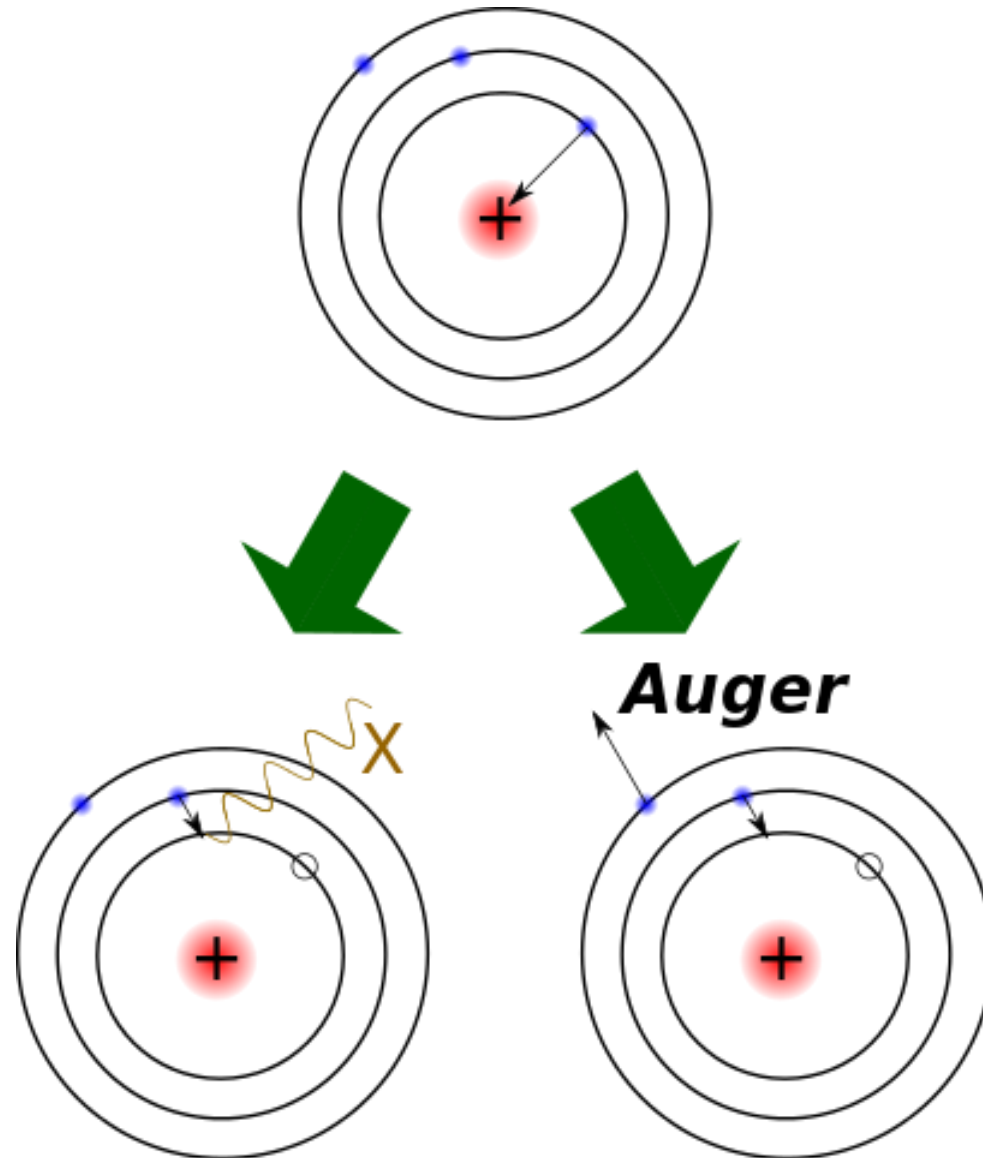
nuclidi dispari-dispari stabili:  
 ${}^2_1\text{H}$ ,  ${}^6_3\text{Li}$ ,  ${}^{10}_5\text{B}$ ,  ${}^{14}_7\text{N}$

**Numeri magici: 2, 6, 8, 20, 28, 50, 82, 126** <sup>Mass number</sup>

# Processi spontanei nei nuclei radioattivi

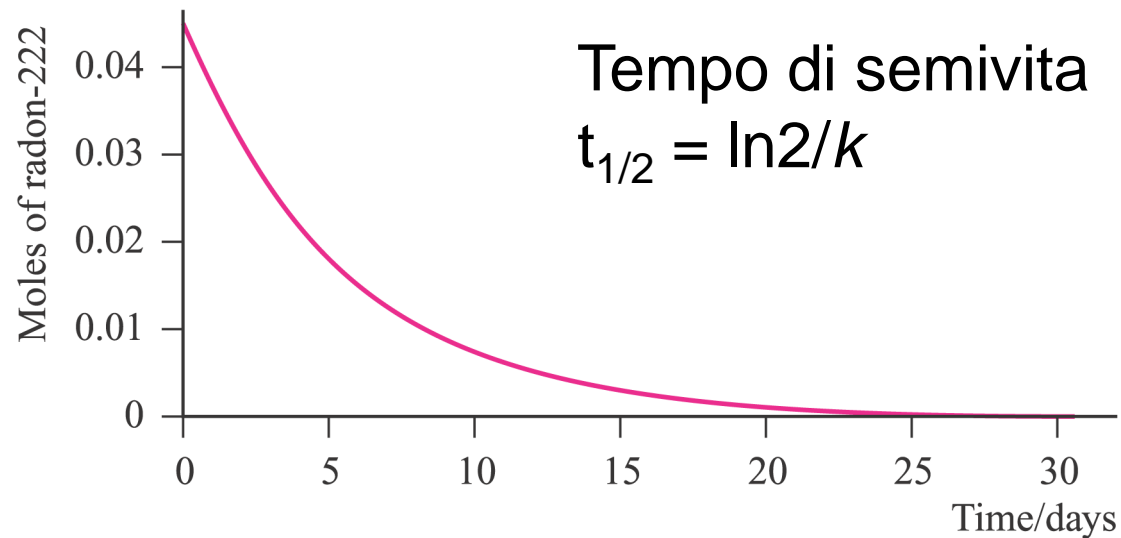
- Emissione di particelle ( $\alpha$ ,  $\beta^-$ ,  $\beta^+$ )
- Emissione di radiazioni (raggi X,  $\gamma$ )
- Cattura di elettroni
- Fissione

# Electron capture (EC)



# Decadimento radioattivo del primo ordine di $^{222}\text{Rn}$

$$N/N_0 = e^{-kt}$$



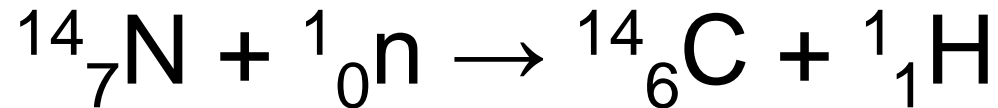
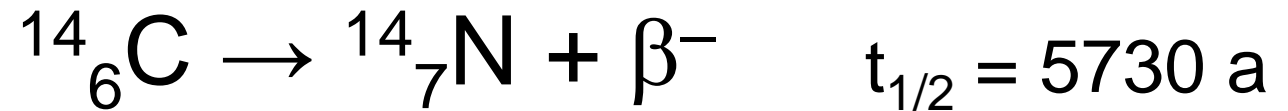
$$\ln N - \ln N_0 = -kt$$

$$\ln N/2 - \ln N = -kt_{1/2}$$

$$\ln 2 = kt_{1/2}$$

$$t_{1/2} = \ln 2/k$$

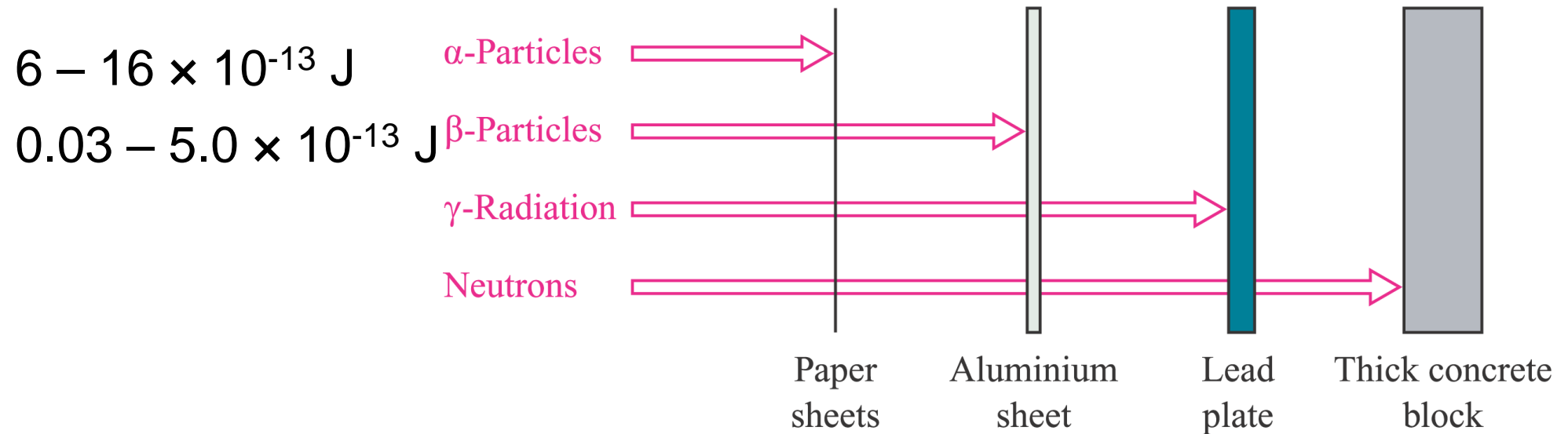
# Datazione con il carbonio-14



Radiazioni cosmiche




1 becquerel (Bq) = una disintegrazione nucleare per secondo

1 Ci (Curie) =  $3.7 \times 10^{10}$  Bq



# Tavola periodica con gli elementi colorati secondo l'emivita del loro isotopo più stabile

		Group																		
		I	II											III	IV	V	VI	VII	VIII	
1		1 H																		2 He
2		3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne	
3		11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar	
4		19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr	
5		37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe	
6		55 Cs	56 Ba	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn	
7		87 Fr	88 Ra	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Uut	114 Fl	115 Uup	116 Lv	117 Uus	118 Uuo	
* Lanthanides		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu				
** Actinides		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr				

-  Elementi stabili
-  Elementi radioattivi con isotopi di emivita > 4 milioni di anni. Radioattività molto piccola, se non trascurabile
-  Elementi radioattivi che possono presentare bassi rischi per la salute. I loro isotopi più stabili hanno emivite tra 800 e 34 000 anni.



# Tavola periodica con il numero degli isotopi stabili

1 H 1																	2 He 2																												
3 Li 3	4 Be 2																	5 B 5	6 C 2	7 N 2	8 O 3	9 F 1	10 Ne 2																						
11 Na 1	12 Mg 3																	13 Al 1	14 Si 3	15 P 1	16 S 4	17 Cl 2	18 Ar 4																						
19 K 2	20 Ca 4	21 Sc 0	22 Ti 2	23 V 1	24 Cr 3	25 Mn 1	26 Fe 4	27 Co 1	28 Ni 2	29 Cu 2	30 Zn 4	31 Ga 2	32 Ge 3	33 As 1	34 Se 4	35 Br 2	36 Kr 6																												
37 Rb 1	38 Sr 4	39 Y 0	40 Zr 2	41 Nb 1	42 Mo 3	43 Tc 0	44 Ru 2	45 Rh 1	46 Pd 2	47 Ag 1	48 Cd 3	49 In 1	50 Sn 4	51 Sb 1	52 Te 2	53 I 1	54 Xe 6																												
55 Cs 1	56 Ba 2	57 La 0	72 Hf 2	73 Ta 1	74 W 3	75 Re 1	76 Os 2	77 Ir 1	78 Pt 2	79 Au 1	80 Hg 2	81 Tl 1	82 Pb 4	83 Bi 1	84 Po 0	85 At 0	86 Rn 6																												
87 Fr 0	88 Ra 0	89-90 Ac 0	91-92 Th 0	93-94 Pa 0	95-96 U 0	97-98 Np 0	99-100 Pu 0	101-102 Am 0	103-104 Cm 0	105-106 Bk 0	107-108 Cf 0	109-110 Es 0	111-112 Fm 0	113-114 Md 0	115-116 No 0	117-118 Lr 0																													
<table border="1"> <tr> <td>58 Ce 2</td> <td>59 Pr 1</td> <td>60 Nd 2</td> <td>61 Pm 0</td> <td>62 Sm 2</td> <td>63 Eu 1</td> <td>64 Gd 2</td> <td>65 Tb 1</td> <td>66 Dy 2</td> <td>67 Ho 1</td> <td>68 Er 2</td> <td>69 Tm 1</td> <td>70 Yb 2</td> <td>71 Lu 1</td> </tr> <tr> <td>90 Th 0</td> <td>91 Pa 0</td> <td>92 U 0</td> <td>93 Np 0</td> <td>94 Pu 0</td> <td>95 Am 0</td> <td>96 Cm 0</td> <td>97 Bk 0</td> <td>98 Cf 0</td> <td>99 Es 0</td> <td>100 Fm 0</td> <td>101 Md 0</td> <td>102 No 0</td> <td>103 Lr 0</td> </tr> </table>																		58 Ce 2	59 Pr 1	60 Nd 2	61 Pm 0	62 Sm 2	63 Eu 1	64 Gd 2	65 Tb 1	66 Dy 2	67 Ho 1	68 Er 2	69 Tm 1	70 Yb 2	71 Lu 1	90 Th 0	91 Pa 0	92 U 0	93 Np 0	94 Pu 0	95 Am 0	96 Cm 0	97 Bk 0	98 Cf 0	99 Es 0	100 Fm 0	101 Md 0	102 No 0	103 Lr 0
58 Ce 2	59 Pr 1	60 Nd 2	61 Pm 0	62 Sm 2	63 Eu 1	64 Gd 2	65 Tb 1	66 Dy 2	67 Ho 1	68 Er 2	69 Tm 1	70 Yb 2	71 Lu 1																																
90 Th 0	91 Pa 0	92 U 0	93 Np 0	94 Pu 0	95 Am 0	96 Cm 0	97 Bk 0	98 Cf 0	99 Es 0	100 Fm 0	101 Md 0	102 No 0	103 Lr 0																																

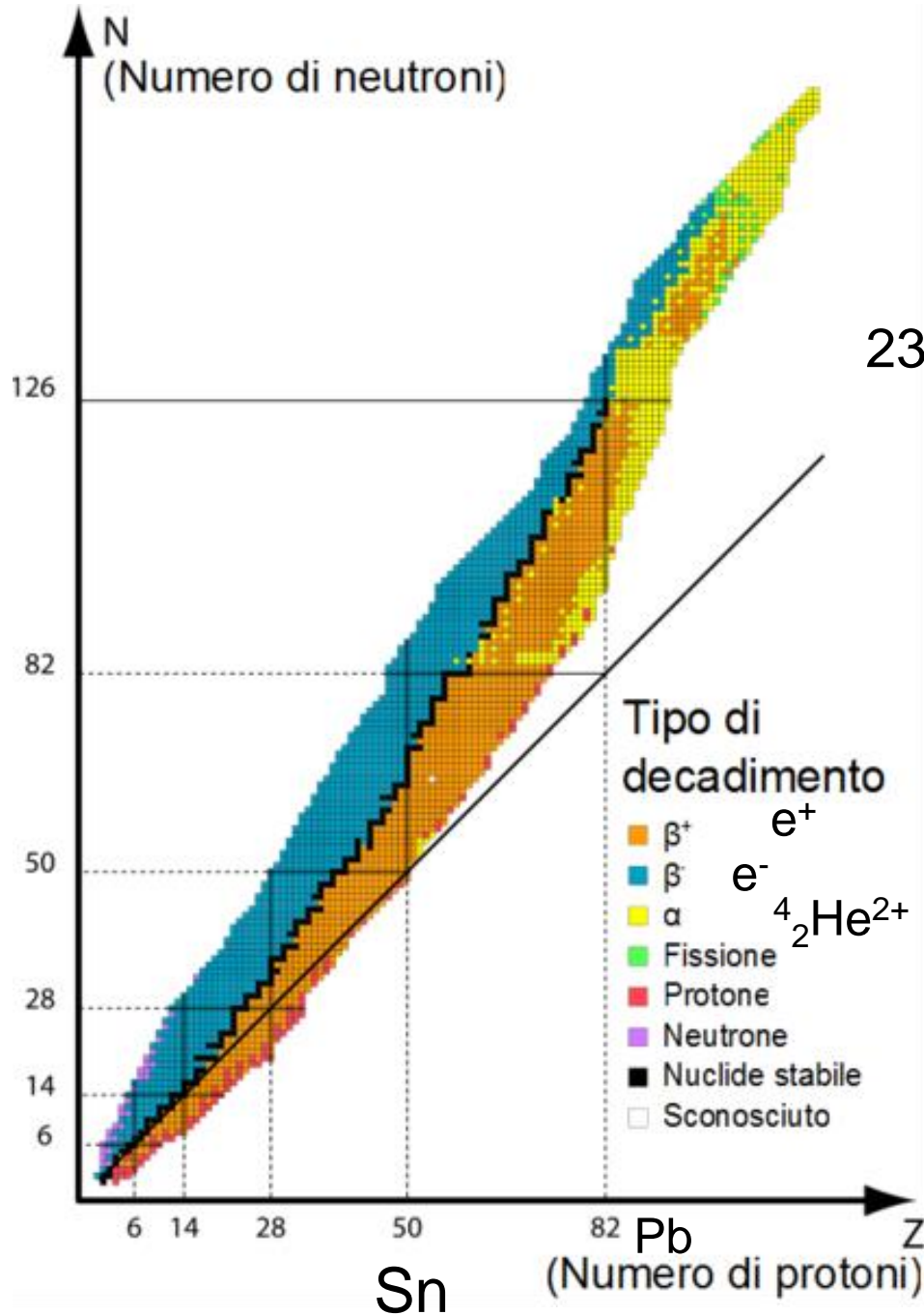
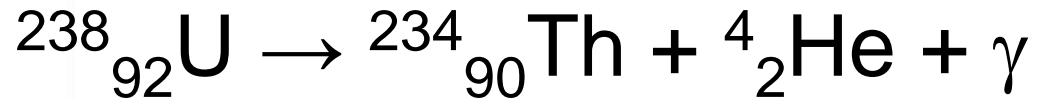
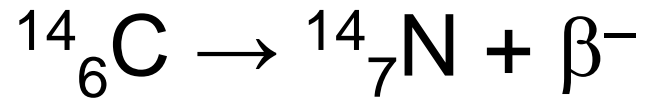
339 nuclidi in natura sulla terra

di cui:

- 255 nuclidi stabili
- 33 nuclidi radioattivi primordiali ( $t_{1/2} > 80$  Ma)
- 51 nuclidi radioattivi ( $t_{1/2} < 80$  Ma) figli o cosmogenici

255+33 = 288 nuclidi primordiali

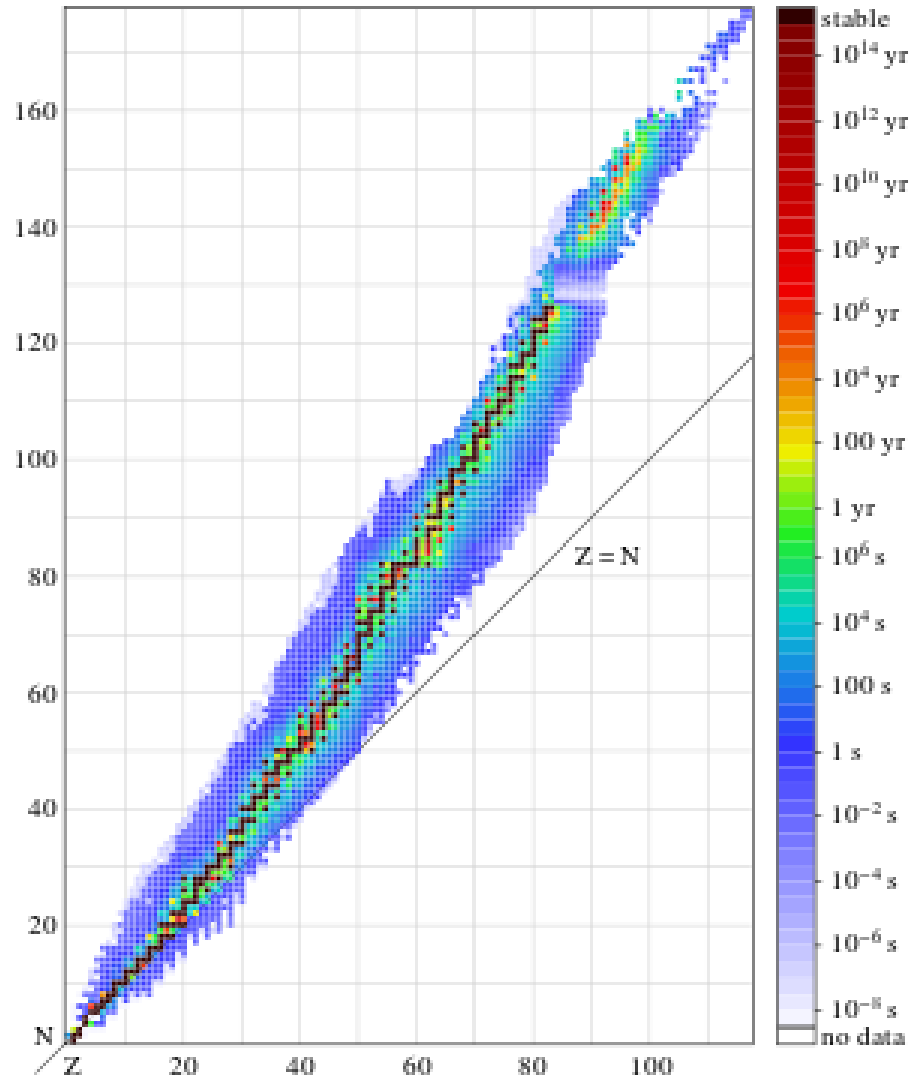
26 elementi con 1 solo nuclide stabile (25 con Z dispari)



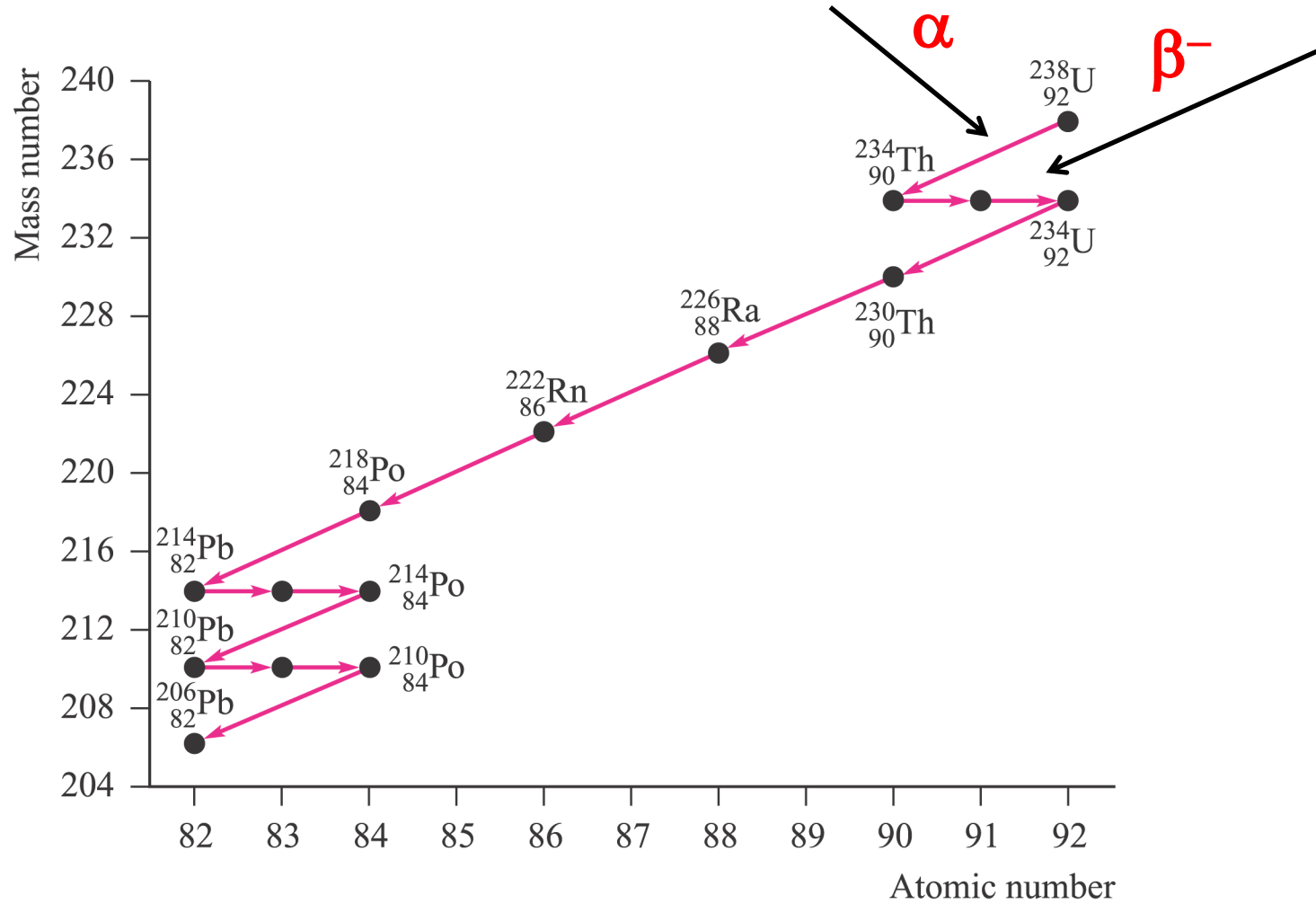
## Live Chart of Nuclides

<https://www-nds.iaea.org/relnsd/vcharthtml/VChartHTML.html>

# Emivite degli isotopi

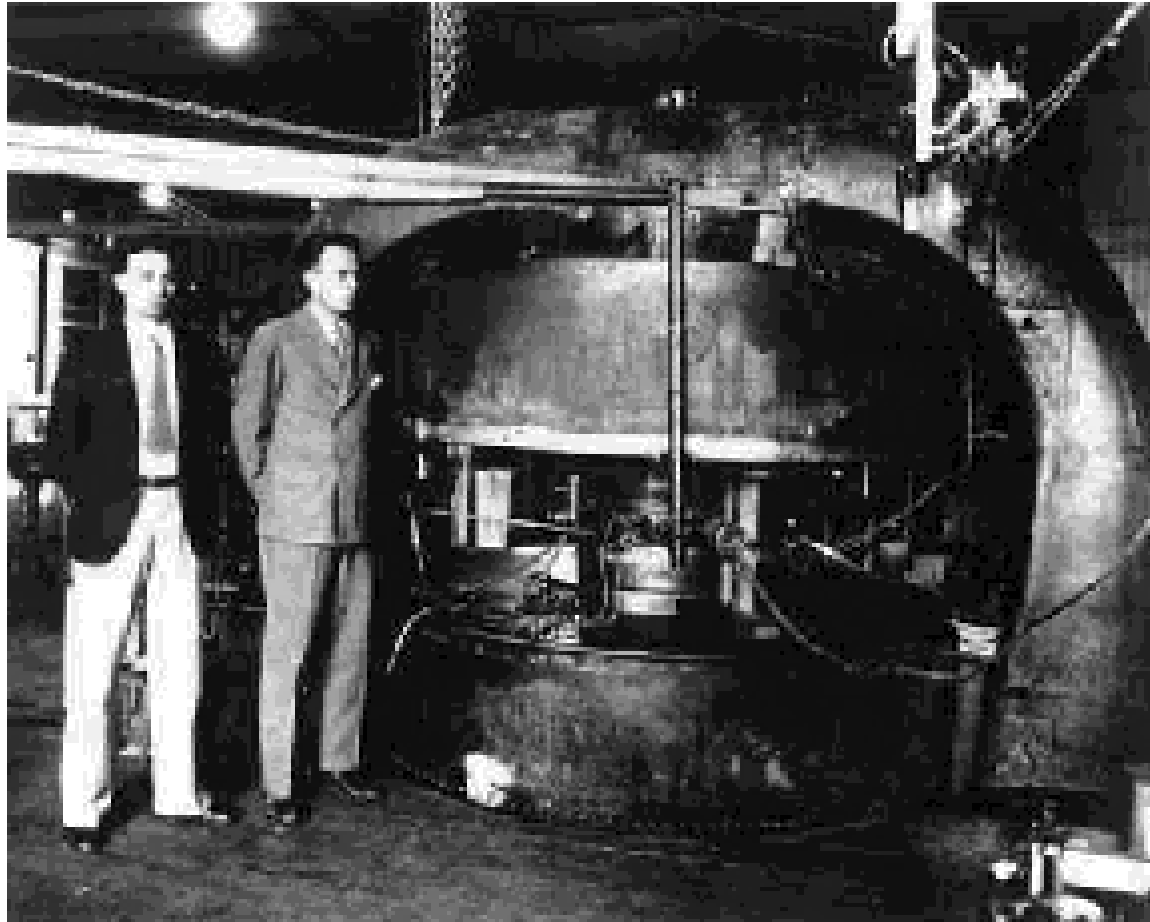


# Decadimento in serie



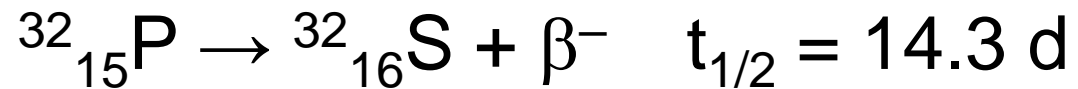
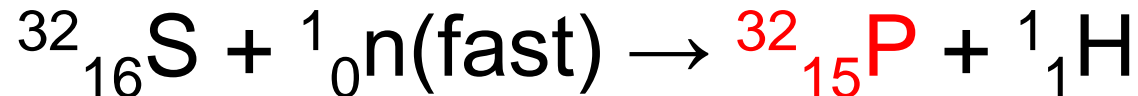
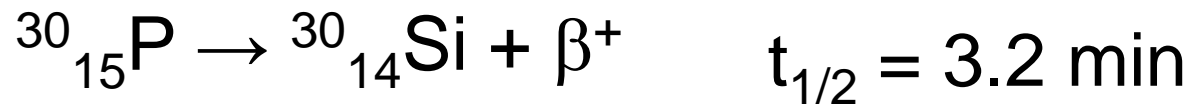
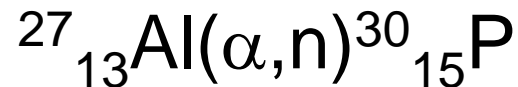
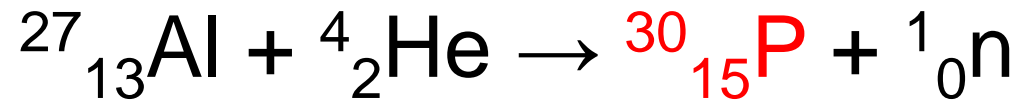
Nuclide	Symbol	Particle emitted	Half-life
Uranium-238	${}_{92}^{238}\text{U}$	$\alpha$	$4.5 \times 10^9$ yr
Thorium-234	${}_{90}^{234}\text{Th}$	$\beta^-$	24.1 d
Protactinium-234	${}_{91}^{234}\text{Pa}$	$\beta^-$	1.18 min
Uranium-234	${}_{92}^{234}\text{U}$	$\alpha$	$2.48 \times 10^5$ yr
Thorium-230	${}_{90}^{230}\text{Th}$	$\alpha$	$8.0 \times 10^4$ yr
Radium-226	${}_{88}^{226}\text{Ra}$	$\alpha$	$1.62 \times 10^3$ yr
Radon-222	${}_{86}^{222}\text{Rn}$	$\alpha$	3.82 d
Polonium-218	${}_{84}^{218}\text{Po}$	$\alpha$	3.05 min
Lead-214	${}_{82}^{214}\text{Pb}$	$\beta^-$	26.8 min
Bismuth-214	${}_{83}^{214}\text{Bi}$	$\beta^-$	19.7 min
Polonium-214	${}_{84}^{214}\text{Po}$	$\alpha$	$1.6 \times 10^{-4}$ s
Lead-210	${}_{82}^{210}\text{Pb}$	$\beta^-$	19.4 yr
Bismuth-210	${}_{83}^{210}\text{Bi}$	$\beta^-$	5.0 d
Polonium-210	${}_{84}^{210}\text{Po}$	$\alpha$	138 d
Lead-206	${}_{82}^{206}\text{Pb}$	None	Non-radioactive

# Il primo ciclotrone (Ciclotrone Lawrence, 1931) Acceleratore di particelle cariche



# Isotopi artificiali

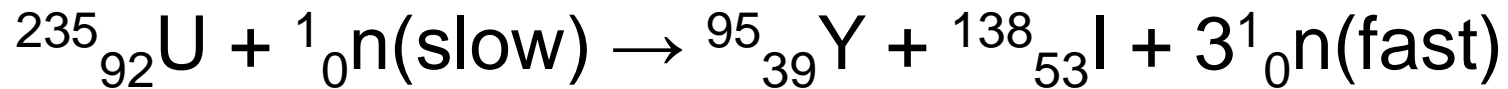
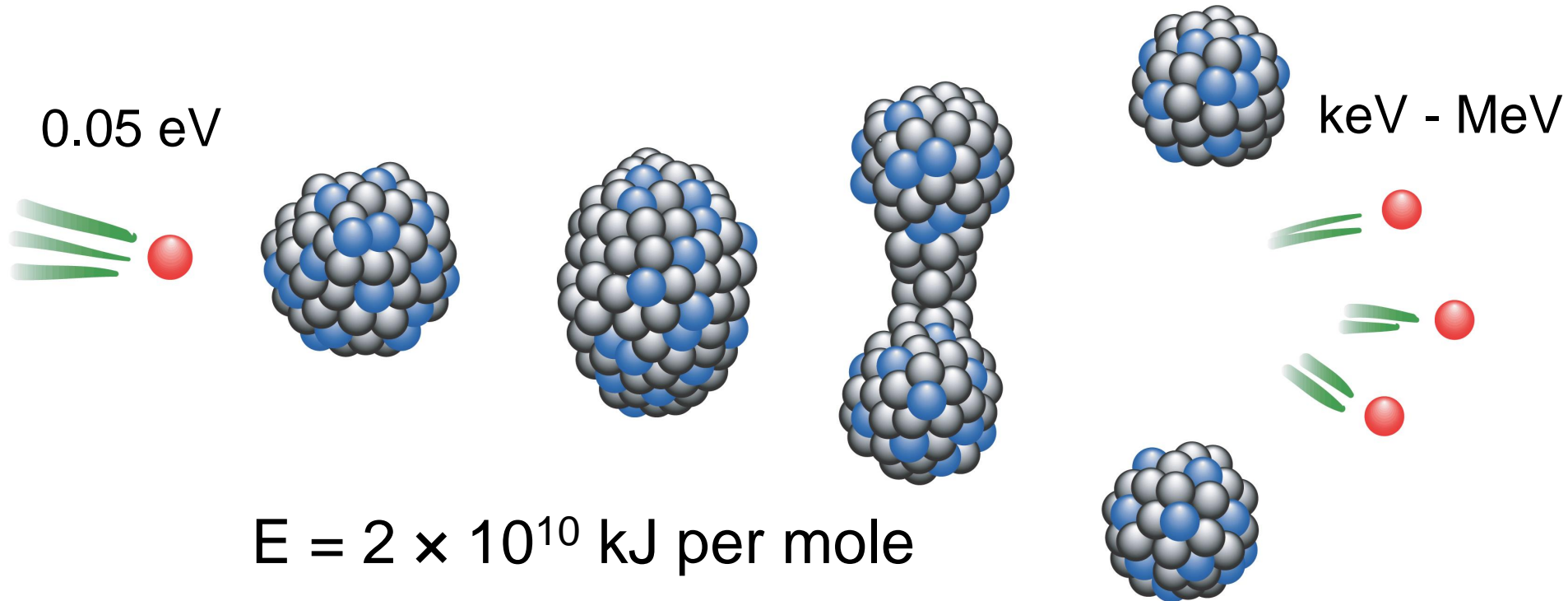
Le reazioni nucleari avvengono con la **conservazione del numero atomico e del numero di massa**



Reazione (n,γ)

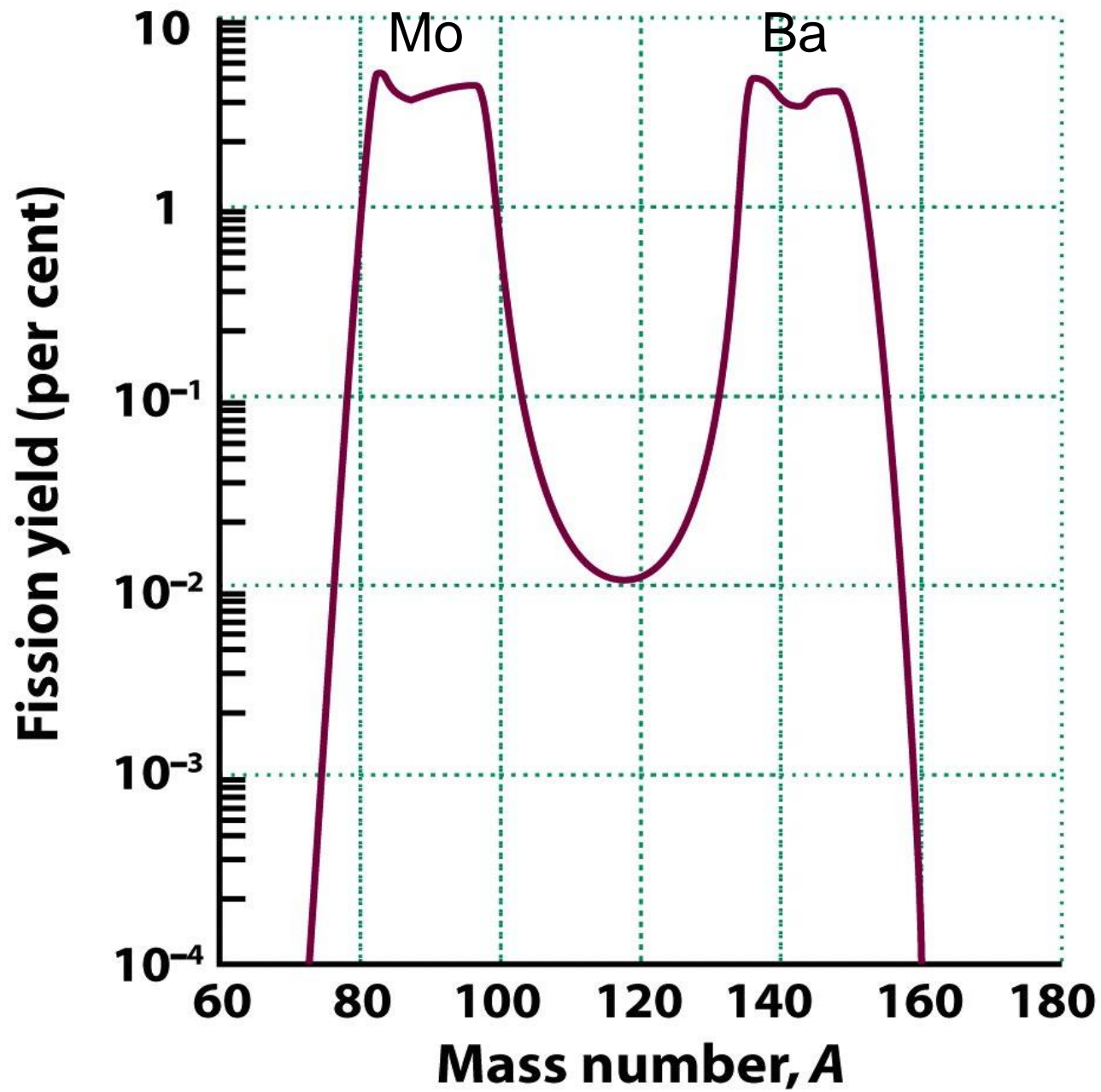
# Reazione (n,γ)

Bombardamento di un nucleo di  $^{235}\text{U}$  con neutroni termici

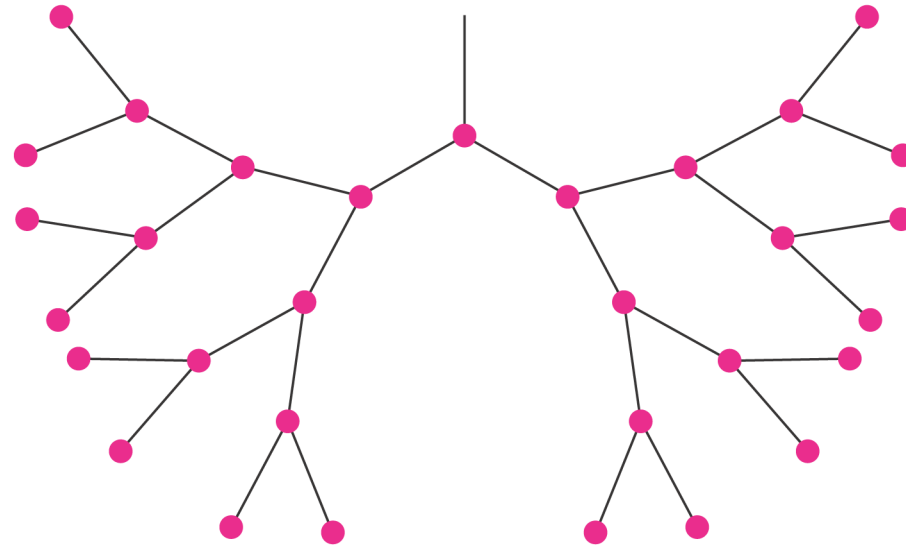


$^{235}\text{U}$  = ca. 0.72% dell'uranio naturale





# Reazione a catena



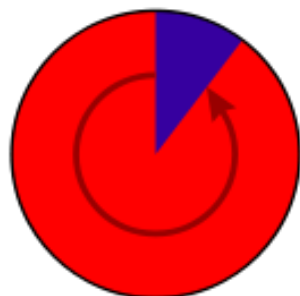
- Grafite o  $D_2O$  per rallentare i neutroni
- Acciaio al boro, carburo di boro o carburo di cadmio per catturare i neutroni (B e Cd hanno alte sezioni d'urto per la cattura)



Natural uranium  
> 99.2% U-238  
0.72% U-235

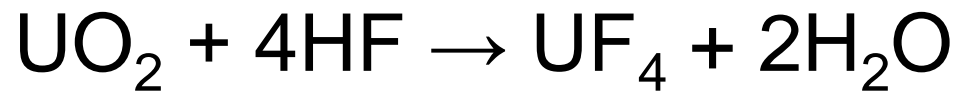
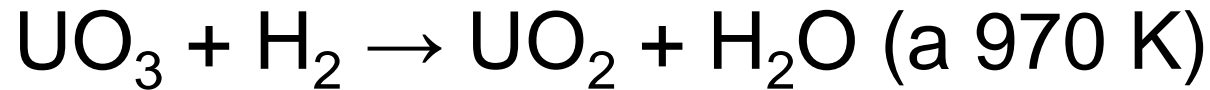


Low-enriched uranium  
(reactor grade)  
3-4% U-235



Highly enriched uranium  
(weapons grade)  
90% U-235

# Trasformazione dell'uranile in UF<sub>6</sub>



Centrifughe per la separazione della miscela di <sup>235</sup>UF<sub>6</sub> e <sup>238</sup>UF<sub>6</sub> sfruttando la legge di Graham

