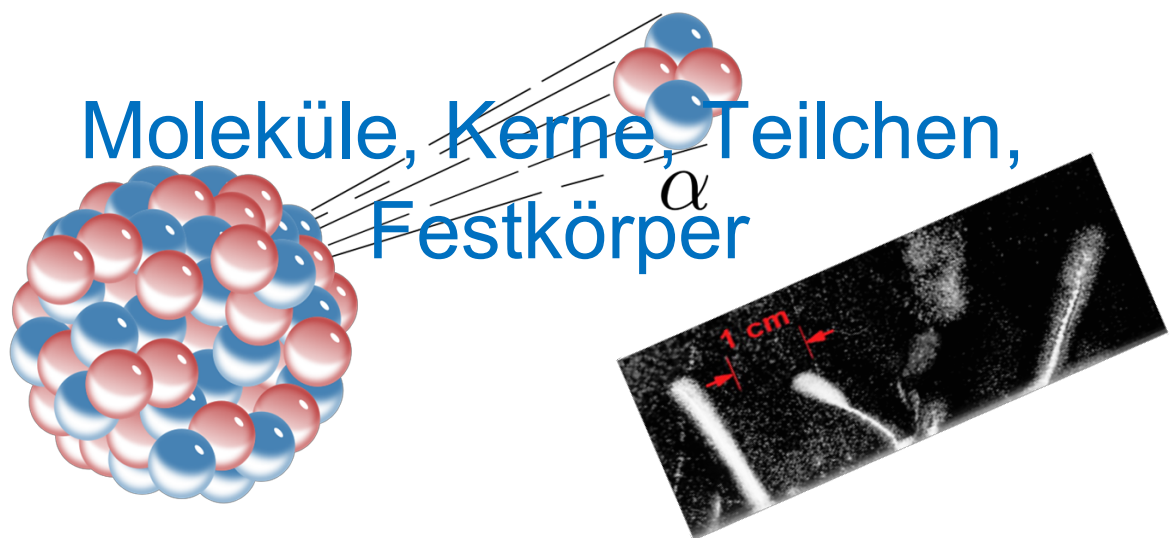
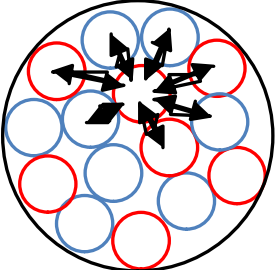
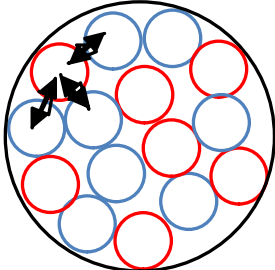


## Experimentalphysik IV

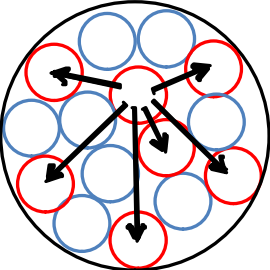


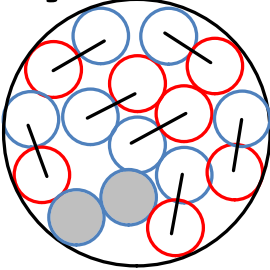
$$E_{\text{bind}} = \text{Volumen} + \text{Oberfläche}$$

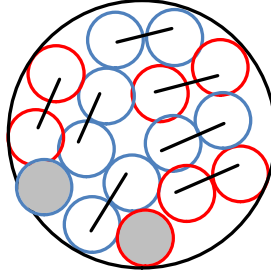

 $\propto A$


 $\propto A^{2/3}$

$$\text{Coulomb} + \text{Asymmetrie} + \text{Paarung}$$


 $\propto Z(Z-1)/A^{1/3}$


 $\propto (A-2Z)^2/A$


 $\pm \delta$

## Weizsäckers Massen Formel (Tröpfchen Modell)

$$m(Z, A) = Z \cdot m_{\text{H}} + (A - Z) \cdot m_{\text{n}} - BE_{\text{Kern}} - BE_{\text{Elektronen}}$$

$$BE_{\text{Kern}} = a_v \cdot A - a_s \cdot A^{2/3} - a_c \cdot \frac{Z(Z-1)}{A^{1/3}} - a_a \cdot \frac{(A-2Z)^2}{A} + \delta$$

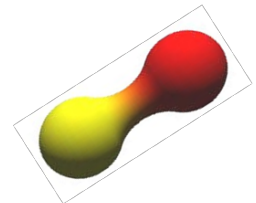
Volumen Energie  $a_v A$  mit  $a_v = 15.56 \text{ MeV}$

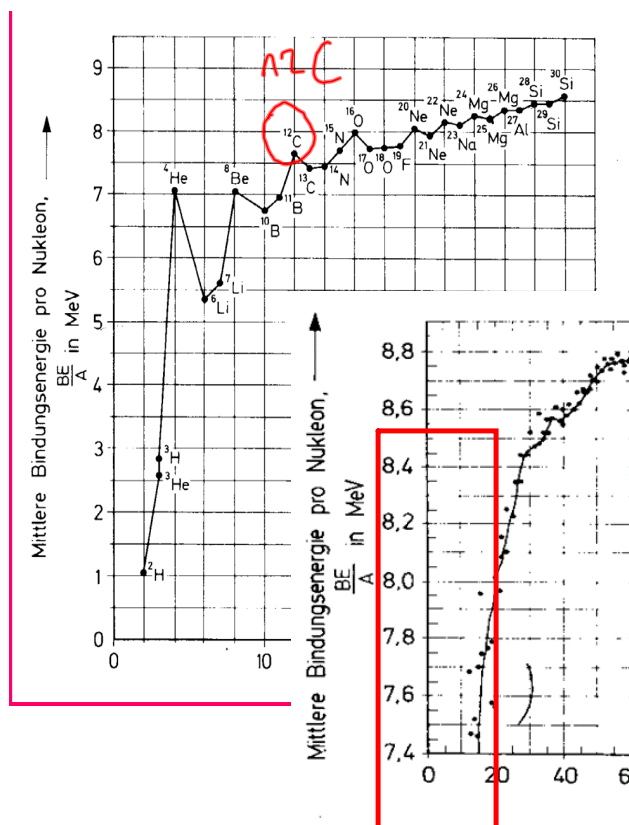
Oberflächen Energie  $a_s A^{2/3}$  mit  $a_s = 17.23 \text{ MeV}$

Coulomb Energie  $a_c \frac{Z(Z-1)}{A^{1/3}}$  mit  $a_c = 0.7 \text{ MeV}$

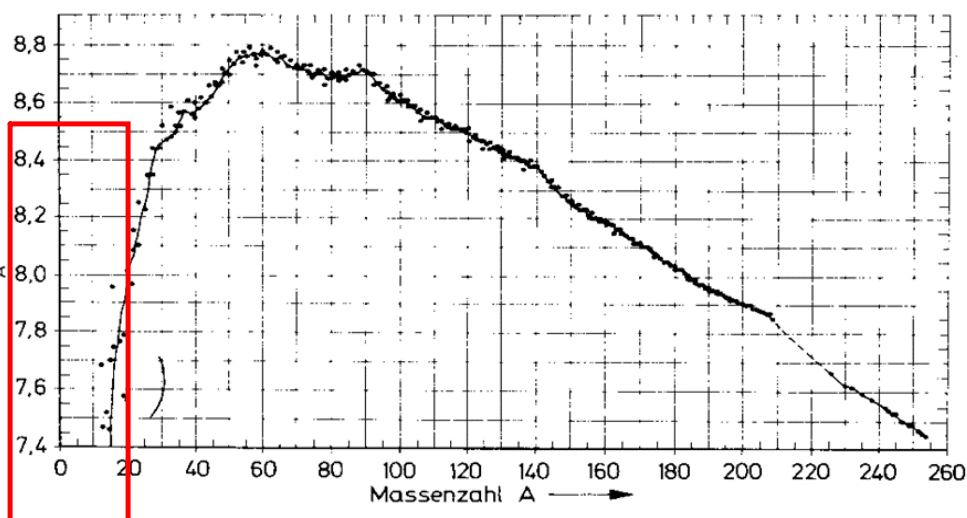
Asymmetrie Energie  $a_a \frac{(A-2Z)^2}{A}$  mit  $a_a = 23.285 \text{ MeV}$

Paarungs Energie  $\delta = \begin{cases} +11/A^{1/2} \text{ MeV} & \text{für gerade - gerade (gg / ee) Kerne} \\ 0 & \text{für ungerade - gerade (ug / oe) Kerne} \\ & \text{gerade - ungerade (gu / eo) Kerne} \\ -11/A^{1/2} \text{ MeV} & \text{für ungerade - ungerade (uu / oo) Kerne} \end{cases}$





## Bindungsenergie pro Nukleon

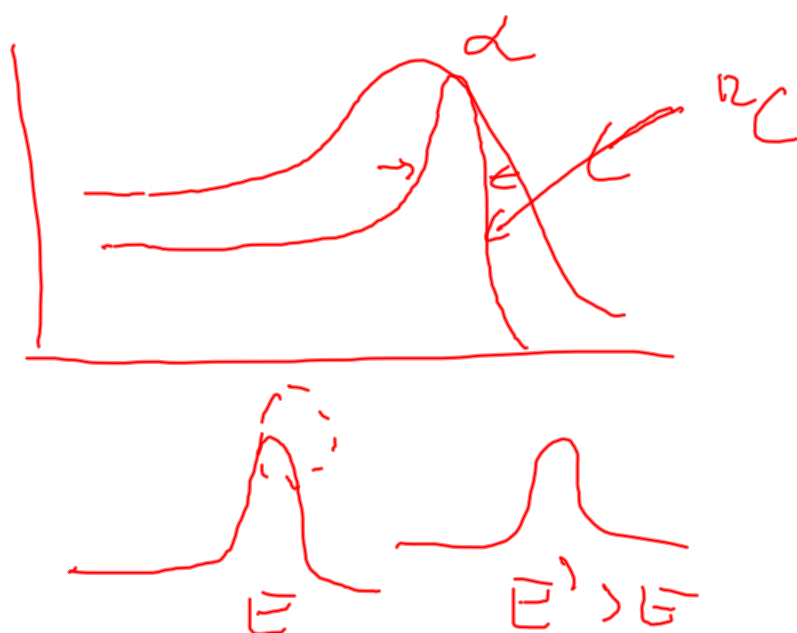


## Bethe Bloch Gleichung

$$-\frac{dE}{ds} = \frac{4\pi \cdot N^V z^2}{m_e v^2} \left( \frac{e^2}{4\pi\epsilon_0} \right)^2 \cdot B \quad B = Z \cdot \left[ \ln \frac{2m_e v^2}{I(1-\beta^2)} - \frac{c_k}{Z} \right]$$

$$\beta = \frac{v}{c} \quad I = 11,5 \cdot Z \text{ (eV)}$$

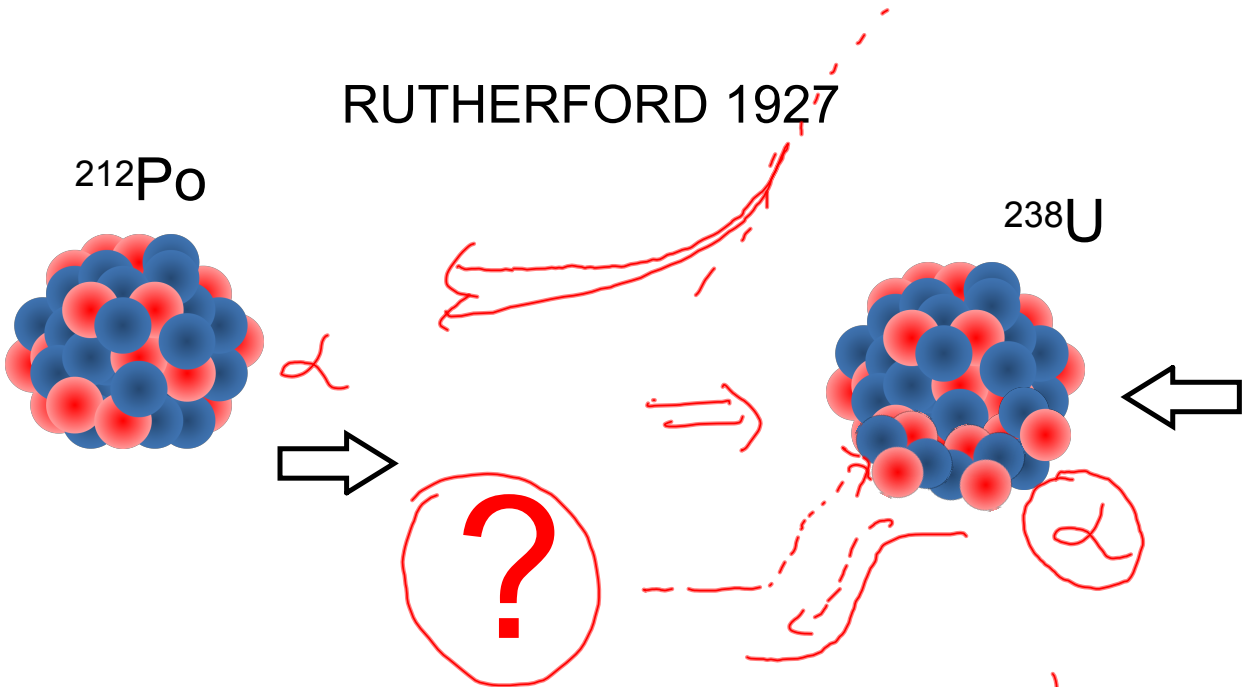
- $-\frac{dE}{ds}$  Bremsvermögen (stopping power)
- $z$  Kernladungszahl des schweren geladenen Teilchens
- $m_e$  Ruhemasse des Elektrons
- $v$  Geschwindigkeit des schweren Teilchens
- $N^V$  Anzahl der Kerne im Absorber pro  $\text{cm}^3$
- $B$  Bremszahl (atomic stopping number)
- $Z$  Kernladungszahl des Absorbers
- $I$  mittleres Ionisationspotential des Absorbers
- $c_k$  Korrektionsfaktor für  $E < 4 \text{ MeV}$ ,  $0 < c_k < 1$ , Umladung





# Alpha Strahlung

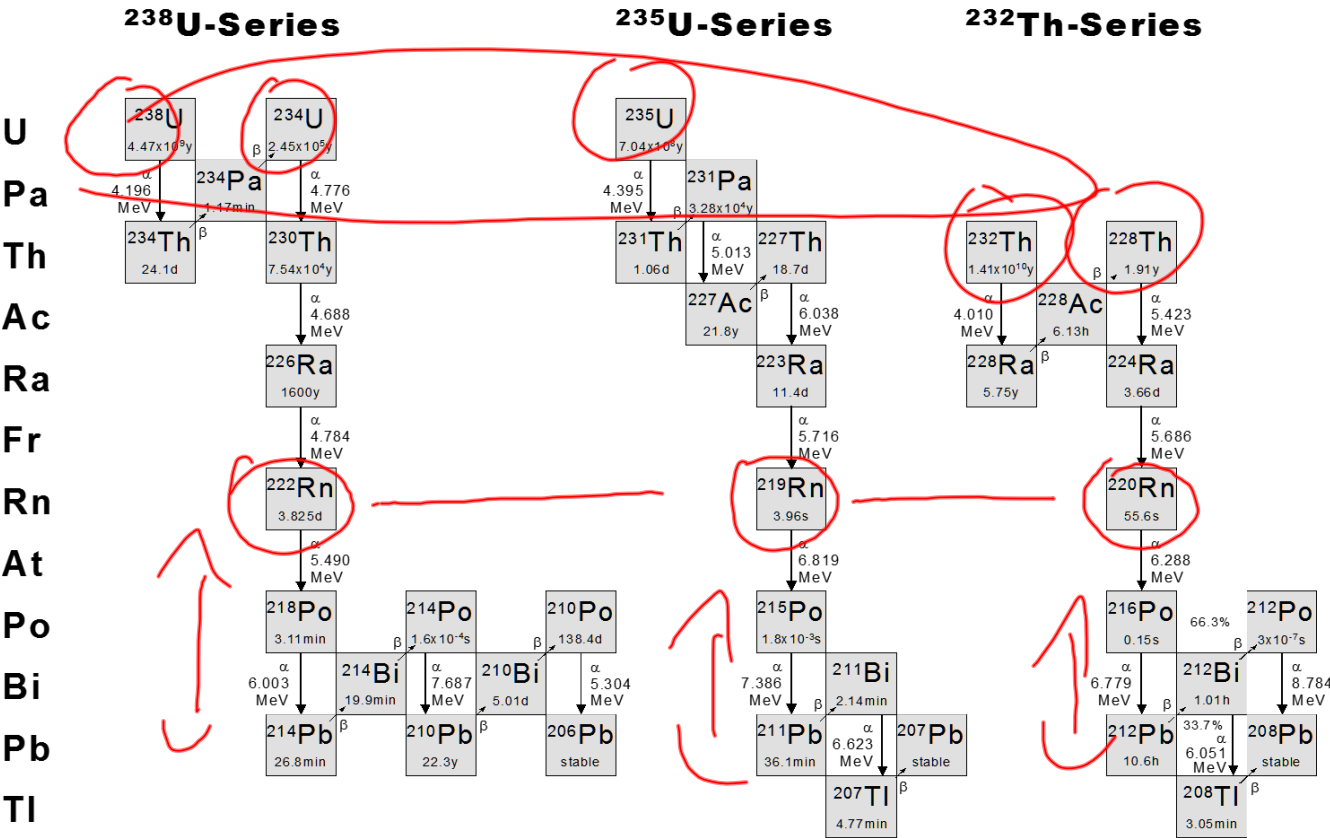


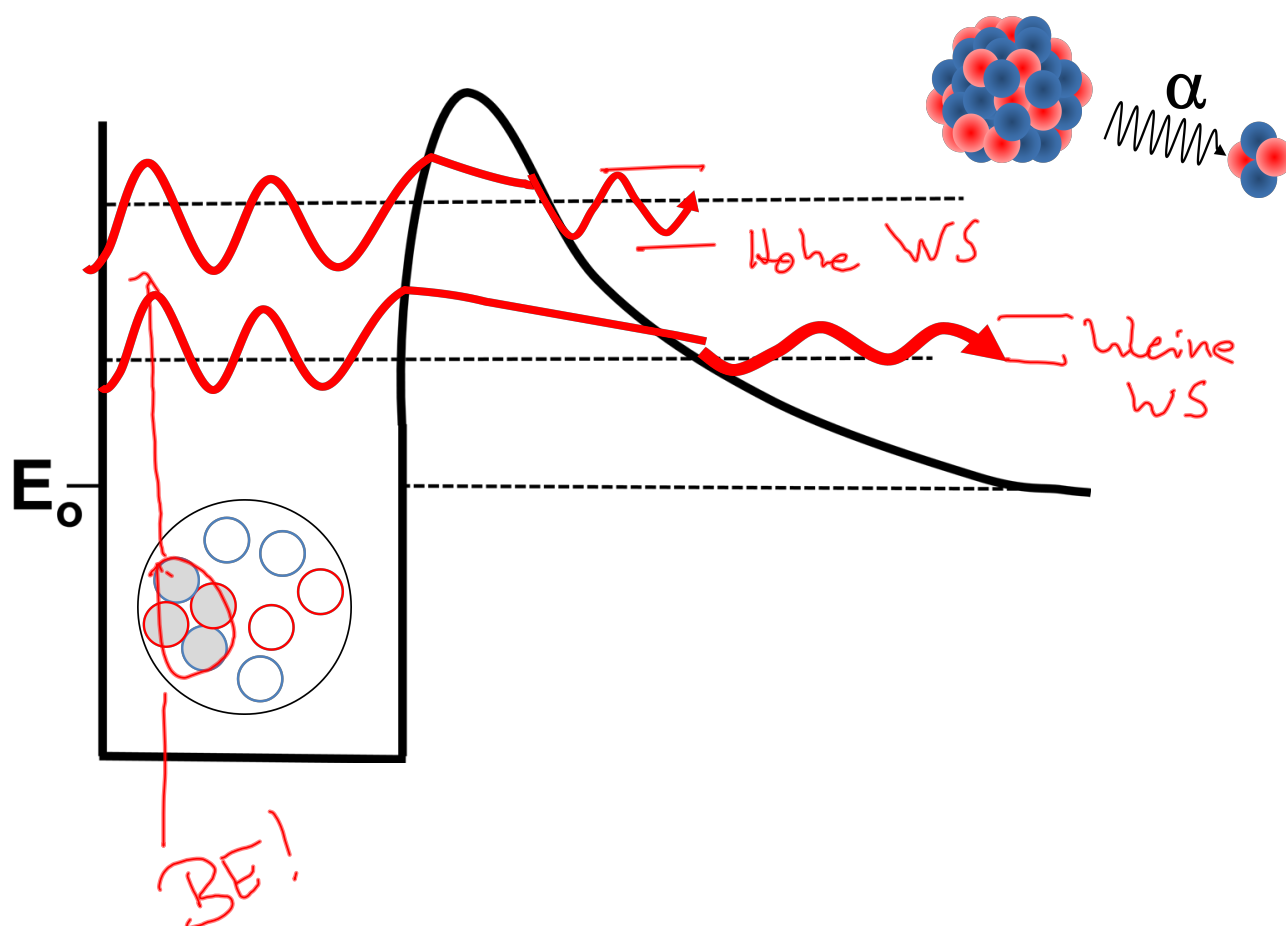


Po 212		
45.1 s	17.1 ns	0.3 μs
α	IT 120	
11.65...	γ 727	
γ 2615	405	
583	223	
IT	α 10.22	α 8.785

U 238	
99.2742	
280 ns	4.468 · 10 <sup>9</sup> a
IT	α 4.198...
2513...	γ (50...), e <sup>-</sup>
γ 1879...	sf, 2β <sup>-</sup> , σ 2.7
sf	σ <sub>f</sub> 3E-6









## Gamow Theorie 1



$$\lambda \equiv \frac{1}{\tau} = \lambda_0 \cdot T_\alpha \propto T_\alpha$$

↗ ↖

Theoretische Bestimmung schwierig  
Hängt von Kernstruktur ab

Transmission durch  
Potentialbarriere

$$T_\alpha \approx e^{-G} \quad \text{G: Gamov Faktor}$$



## Gamow Theorie 2



$$\frac{1}{\lambda} \propto \frac{1}{T_{\alpha}} \tau \propto t_{1/2} \propto e^G$$

$$G \propto \frac{1}{\sqrt{E_{\alpha}}}$$

$$\ln(t_{1/2}) \propto \frac{1}{\sqrt{E_{\alpha}}}$$



## Gamow Theorie 3



$$\frac{1}{\lambda} \propto \frac{1}{T_{\alpha}} \tau \propto t_{1/2} \propto e^G$$

$$G \propto \frac{1}{\sqrt{E_{\alpha}}}$$

$$\ln(t_{1/2}) \propto \frac{1}{\sqrt{E_{\alpha}}}$$

Nuklid	$T_{1/2}$	$E_{\alpha}$	$T_{\alpha}$
$^{212}\text{Po}$	0,3 ms	8,78 MeV	$1,32 \cdot 10^{-13}$
$^{224}\text{Ra}$	3,6 d	5,7 MeV	$5,9 \cdot 10^{-26}$
$^{144}\text{Nd}$	$2 \cdot 10^{15}$ a	1,83 MeV	$2,18 \cdot 10^{-42}$



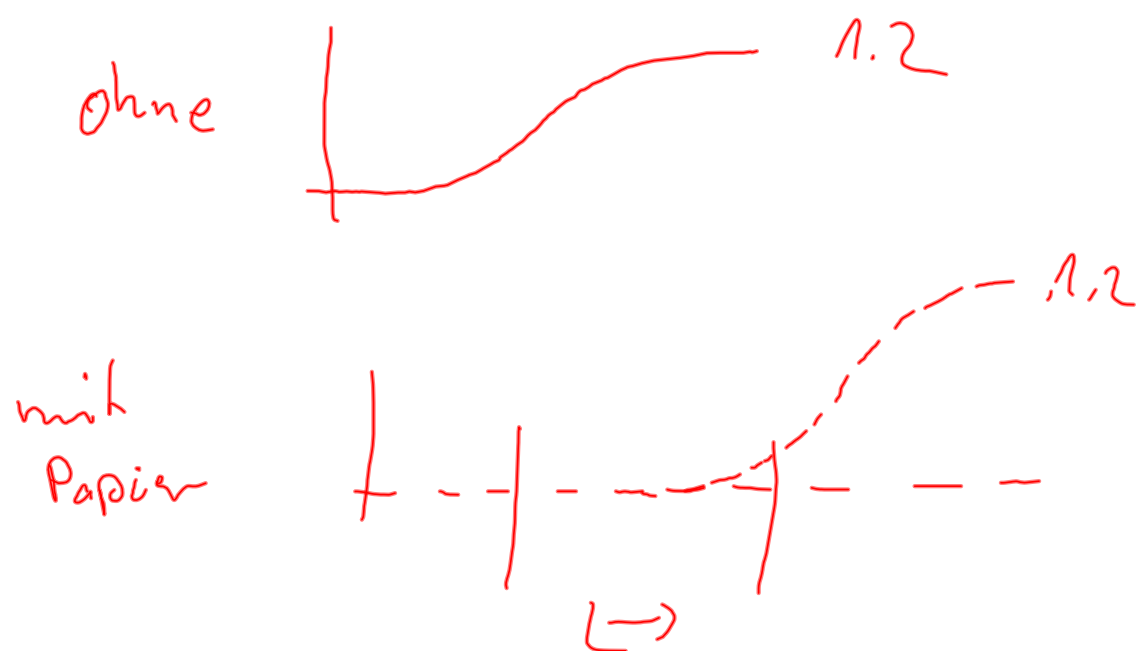
Long range alphas

Ac 215 0.17 s	Ac 216 0.44 ms	Ac 217 0.74 μs 69 ns	Ac 218 1.1 μs	Ac 219 11.8 μs	Ac 220 26 ms	Ac 221 52 ms	Ac 222 63 s 5.0 s	Ac 223 2.10 m	Ac 224 2.9 h
α 9.029; 9.105... γ 83; 954; γ (396...)	α 9.029; 9.105... γ 83; 954; γ 771...	h <sub>β</sub> 660; 480; 382; α 10.54... α 9.65	α 9.205 g	α 8.664	α 7.85; 7.61; 7.68... γ 134...	α 7.65; 7.44; 7.38...	α 6.647; 6.662; α 7.009; 6.663; γ 199; 191; 6...	α 6.142; 6.060; 6.214... γ 205; 154; 324... C 14; α 130; α <0.7	α 6.142; 6.060; 6.214... γ 205; 154; 324... C 14; α 130; α <0.7
Ra 214 2.46 s	Ra 215 1.67 ms	Ra 216 2.0 ns 0.16 μs	Ra 217 1.6 μs	Ra 218 25.6 μs	Ra 219 10 ms	Ra 220 23 ms	Ra 221 28 s	Ra 222 2.10 m	Ra 223 11.43 d
α 7.137; 6.505 γ 642	α 8.700; 7.879... γ 834; 540	h <sub>β</sub> 660; 480; 382; α 10.54... α 9.65	α 8.99	α 8.39 g	α 7.679; 7.989... γ 316; 214; 592...	α 7.46... γ 465	α 6.613; 6.761; 6.663; γ 149; 93; 174 C 14	α 6.613; 6.761; 6.663; γ 149; 93; 174 C 14	α 5.7162; 5.6067... γ 205; 154; 324... C 14; α 130; α <0.7
Fr 213 34.6 s	Fr 214 3.35 ms 5.0 ms	Fr 215 0.09 μs	Fr 216 0.70 μs	Fr 217 16 μs	Fr 218 22 ms 1.0 ms	Fr 219 21 ms	Fr 220 27.4 s	Fr 221 4.9 m	Fr 222 14.2 m
α 6.775	α 8.477; 8.426; 8.547... 8.356...	α 9.36	α 9.01 g	α 8.315	α 7.615; 7.600; 7.605... m; g h <sub>γ</sub>	α 7.607; 7.576... g	α 7.312... γ (352; 517...)	α 6.619; 6.663; α 6.58... γ 106; 162...	α 5.7162; 5.6067... γ 205; 154; 324... C 14; α 130; α <0.7
Rn 212 24 m	Rn 213 19.5 ms	Rn 214 65 ms 0.7 ns 0.37 μs	Rn 215 2.3 μs	Rn 216 45 μs	Rn 217 0.54 ms	Rn 218 35 s	Rn 219 3.96 s	Rn 220 55.6 s	Rn 221 25 m
α 6.264...	α 8.088; 7.252... γ 540...	h <sub>β</sub> 660; 480; 382; α 10.54... α 9.65	α 8.67 g	α 8.05 g	α 7.740...	α 7.488; 7.591... γ (115; 418...)	α 6.819; 6.553; 6.425... γ 271; 402...	α 6.288... γ (550) α <0.2	β <sup>-</sup> 0.8; 1.1... α 6.037; 5.788; 5.778 γ 186; 150...
At 211 7.22 h	At 212 119 ms 314 ms	At 213 0.11 μs	At 214 0.76 μs 0.27 μs 0.56 μs	At 215 0.1 ms	At 216 ? 0.3 ms	At 217 32.3 ms	At 218 ~2 s	At 219 0.9 m	At 220 3.71 m
α 5.867... γ (687...)	α 7.84; 7.90... γ 63... e <sup>-</sup>	α 9.06	α 8.782; 8.819... m; g γ	α 8.026... γ (405)	α 7.488; 7.591... γ (115; 418...)	α 7.069... β <sup>-</sup> ... γ (259; 334; 595...)	α 6.694; 6.653... β <sup>-</sup> ...	α 6.27	β <sup>-</sup> ... α 5.493 γ 241; 293; 422...
Po 210 138.38 d	Po 211 25.2 s 0.516 s	Po 212 45.1 s 17.1 ns 0.3 μs	Po 213 4.2 μs	Po 214 1.7 ms	Po 215 1.78 ms	Po 216 0.15 s	Po 217 1.53 s	Po 218 3.05 m	Po 219 >300 ns
α 5.30438... γ (803); α <0.0005 + <0.030; α <sub>0</sub> α 0.002; α <sub>1</sub> <0.1	α 7.275; 8.893... γ 570; 1064... h <sub>γ</sub>	α 11.65; h <sub>γ</sub> 729; γ 205; 154; 563; α 10... α 10...	α 8.376... γ (779)	α 7.3962... β <sup>-</sup> ... γ (439...)	α 6.7783... γ (805)	α 6.543 β <sup>-</sup>	α 6.0024... β <sup>-</sup> ...	α 6.0024... β <sup>-</sup> ...	β <sup>-</sup> ... α 5.493 γ 241; 293; 422...
Bi 209 100	Bi 210 3.0·10 <sup>10</sup> a	Bi 211 2.17 m	Bi 212 25 m 60.6 m	Bi 213 45.59 m	Bi 214 19.9 m	Bi 215 36.9 s 7.7 m	Bi 216 3.6 m 2.17 m	Bi 217 98.5 s	Bi 218 33 s
α 3.137 α 0.011 + 0.023 α <sub>0</sub> α <3E-7	α 7.450; γ 305; 265	α 6.6229; 6.2788 γ 351... α → g; β <sup>-</sup> → g	β <sup>-</sup> 1.4... α 5.87... γ 440; (293; 1100...)	β <sup>-</sup> 1.5; 3.3... α 5.450; 5.513... γ 609; 1764; 1120... β <sub>0</sub> α 9.079...	h <sub>γ</sub> 414; 748; 187... β <sup>-</sup> ... γ 294; 271; 250; 419... 1105...	β <sup>-</sup> ... γ 550; 419; 300; 419	β <sup>-</sup> ... γ 550; 419; 300; 419	β <sup>-</sup> ... γ 265; 254; 890; 436...	β <sup>-</sup> 3.5; 3.7... γ 510; 386; 426; 263...
Pb 208 52.4	Pb 209 3.253 h	Pb 210 22.3 a	Pb 211 36.1 m	Pb 212 10.64 h	Pb 213 10.2 m	Pb 214 26.8 m			
α 0.00023 α <sub>0</sub> α <8E-6	β <sup>-</sup> 0.6 no γ	β <sup>-</sup> 0.02; 0.08 γ 47; e <sup>-</sup> ; g α 3.72 α <0.5	β <sup>-</sup> 1.4... γ 405; 832; 427...	β <sup>-</sup> 0.3; 0.6... γ 239; 300... g	β <sup>-</sup> 0.7; 1.0... γ 352; 295; 242...				

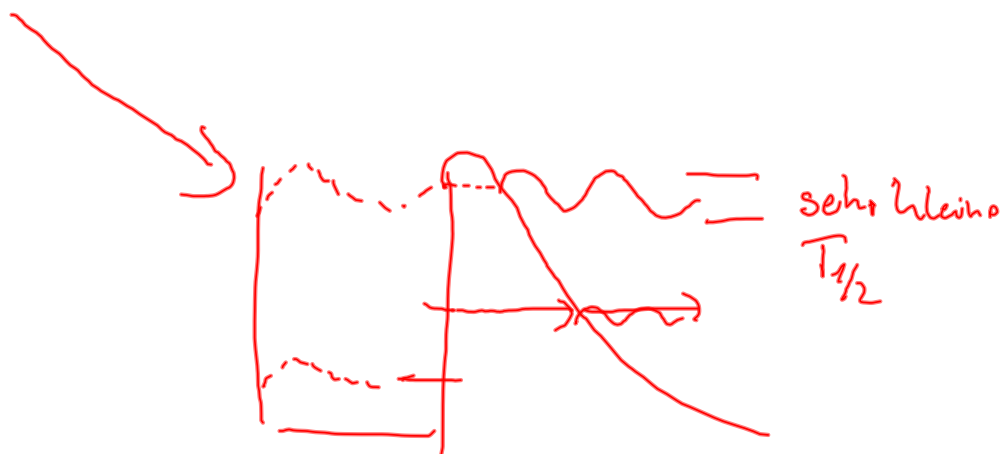


## Long range alphas

<b>Po 210</b> 138.38 d $\alpha$ 5.30438... $\gamma$ (803); $\sigma < 0.0005$ $+ < 0.030$ ; $\sigma_{n,\alpha}$ 0.002; $\sigma_f < 0.1$	<b>Po 211</b> 25.2 s   0.516 s $\alpha$ 7.275; 8.883... $\gamma$ 570; 1064... $t_{1/2}$	<b>Po 212</b> 45.1 s   17.1 ns   0.3 $\mu$ s $\alpha$ 11.65... $t_{1/2}$ 728; $\gamma$ 2615; 406; 583; 223... $t_{1/2}$ $\alpha$ 10.22 $\alpha$ 8.785	<b>Po 213</b> 4.2 $\mu$ s $\alpha$ 8.376... $\gamma$ (779)
<b>Bi 209</b> 100 $1.9 \cdot 10^{19}$ a $\alpha$ 3.137 $\sigma$ 0.011 + 0.023 $\sigma_{n,\alpha} < 3E-7$	<b>Bi 210</b> 3.0 $\cdot 10^6$ a   5.013 d $\alpha$ 4.946; 4.908... $\gamma$ 266; 304... $\sigma$ 0.054	<b>Bi 211</b> 2.17 m $\alpha$ 6.6229; 6.2788 $\beta^-$ ... $\gamma$ 351... $\alpha \rightarrow g$ ; $\beta^- \rightarrow g$	<b>Bi 212</b> 9 m   25 m   60.60 m $\alpha$ 6.34; 6.30 $\beta^-$ ; $\gamma$ $\beta\alpha$ 10.22; 10.11... $\beta^-$ $m_2$ $m_1$ $g$
<b>Pb 208</b> 52.4 $\sigma$ 0.00023 $\sigma_{n,\alpha} < 8E-6$	<b>Pb 209</b> 3.253 h $\beta^-$ 0.6 no $\gamma$	<b>Pb 210</b> 22.3 a $\beta^-$ 0.02; 0.06 $\gamma$ 47; $e^-$ ; $g$ $\alpha$ 3.72 $\sigma < 0.5$	<b>Pb 211</b> 36.1 m $\beta^-$ 1.4... $\gamma$ 405; 832; 427...









## U-235 Decay Chain: Actinium-Chain

