HW: Compute the half-life of:

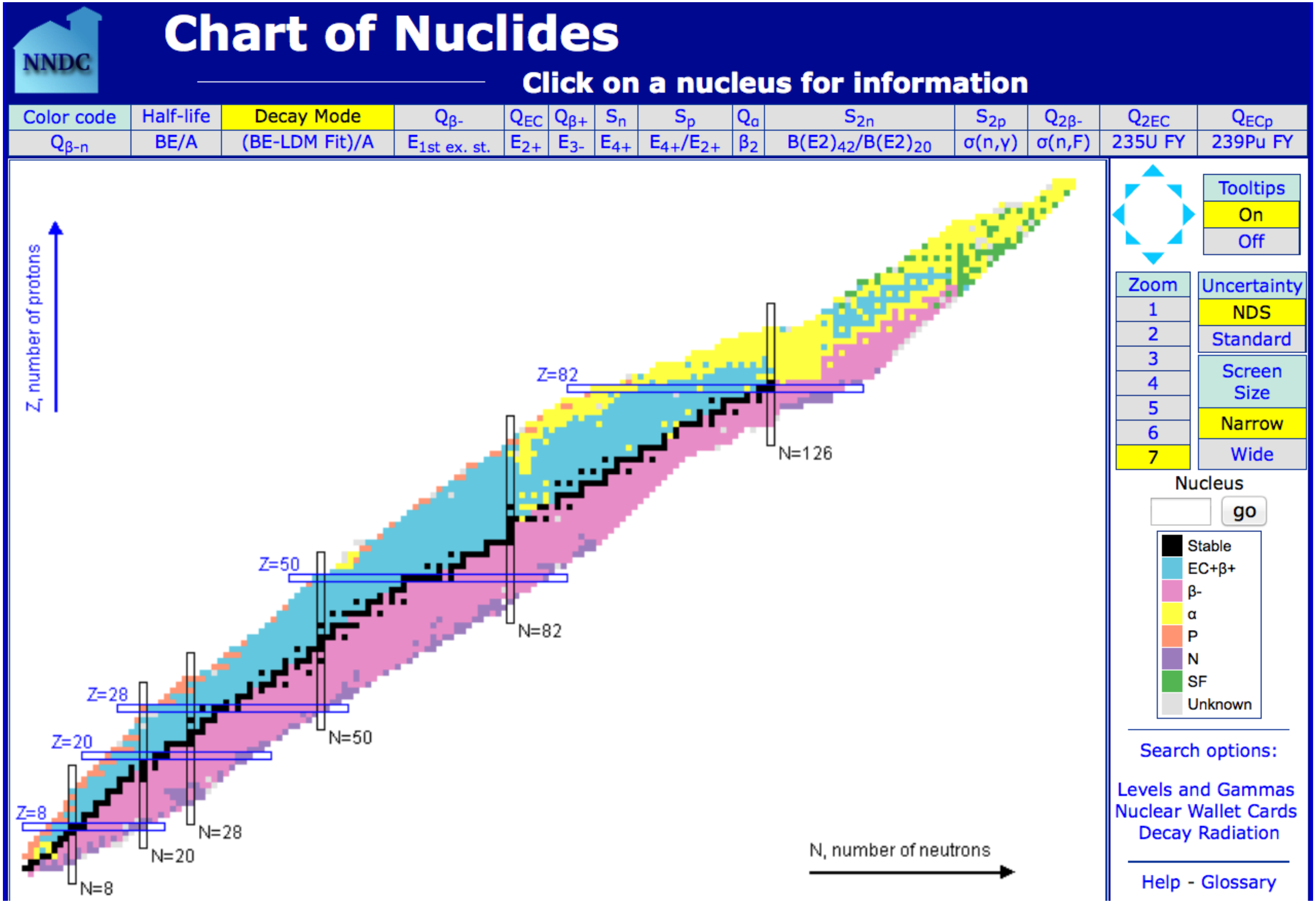
- ^{141}Ho proton emitter (Γ=2·10^{-20} MeV)
- 3^{-} state in ^{10}Be at E=10.16 MeV (Γ=296 keV)
- First 2^{+} state in ^{6}He at E=1.797MeV (Γ=113 keV)
- Hoyle state in ^{12}C at E=7.654 MeV (Γ=8.5 eV)
- ^{8}Be ground state (Γ=5.57 eV)
- Baryon N(1440)1/2^{+} (Γ=350 MeV)

Discuss the result.

$$T_{1/2} = \ln 2 \frac{\hbar}{\Gamma}, \qquad \hbar = 6.58 \cdot 10^{-22}\ \mathrm{MeV} \cdot \mathrm{sec}$$

Alpha decay

Alpha Decay



NNDC
Chart of Nuclides
Click on a nucleus for information
Color code | Half-life | Decay Mode | Qβ- | QEC | Qβ+ | Sn | Sp | Qα | S2n | S2p | Q2β- | Q2EC | QECp
Qβ-n | BE/A | (BE-LDM Fit)/A | E1st ex. st. | E2+ | E3- | E4+ | E4+/E2+ | β2 | B(E2)42/B(E2)20 | σ(n,γ) | σ(n,F) | 235U FY | 239Pu FY
Z, number of protons
N, number of neutrons
Z=8
Z=20
Z=28
Z=50
Z=82
N=8
N=20
N=28
N=50
N=82
N=126
Tooltips
On
Off
Zoom
1
2
3
4
5
6
7
Uncertainty
NDS
Standard
Screen Size
Narrow
Wide
Nucleus
go
Stable
EC+β+
β-
α
P
N
SF
Unknown
Search options:
Levels and Gammas
Nuclear Wallet Cards
Decay Radiation
Help - Glossary

Alpha Decay

Energy relations

$$S_\alpha(A,Z) = -Q_\alpha(A,Z) = B(A,Z) - B(A-4,Z-2) - 28.3\text{MeV}$$

experimental binding energy of ^{4}He

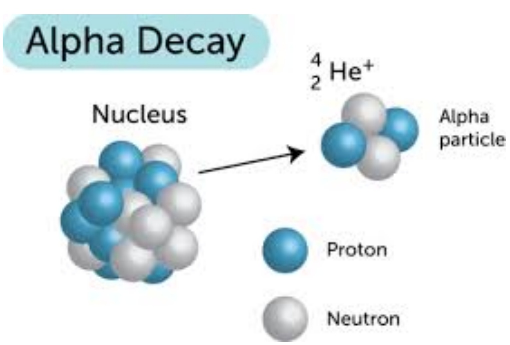
$$Q_\alpha = T_\alpha + T_d =$$

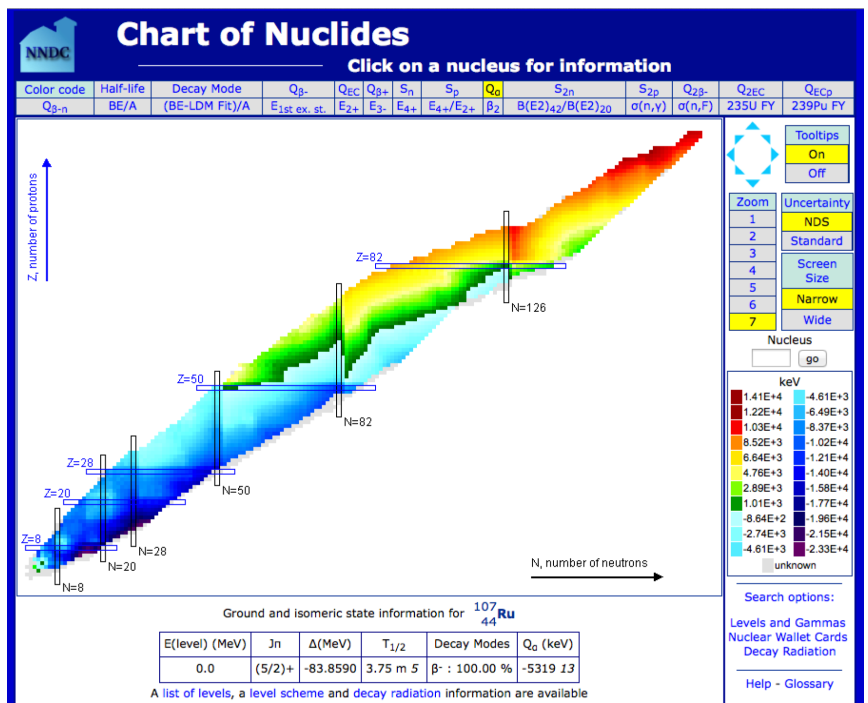
$$T_\alpha\left(\frac{M_D + M_\alpha}{M_D}\right) \approx T_\alpha\left(\frac{A}{A-4}\right)$$

recoil term effect

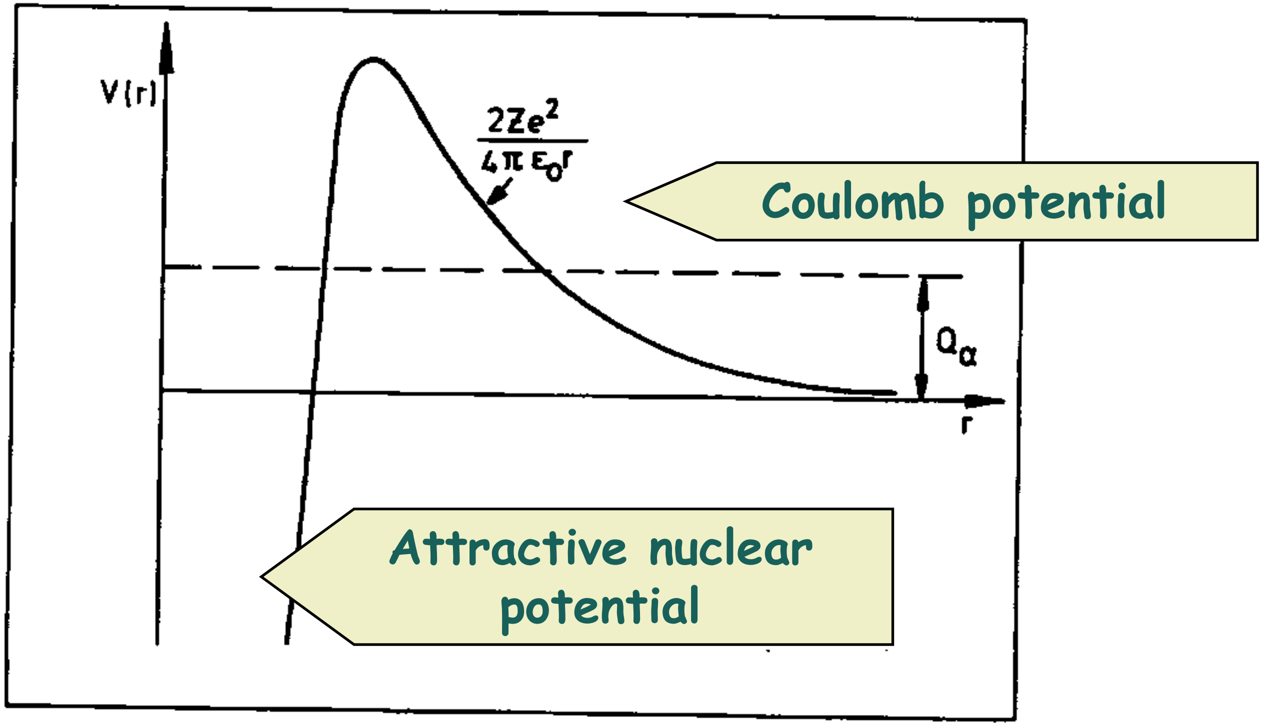
+electron screening
+bremsstrahlung

http://www.nndc.bnl.gov/chart/reColor.jsp?newColor=qa





Theory of Alpha decay: Gamow 1928

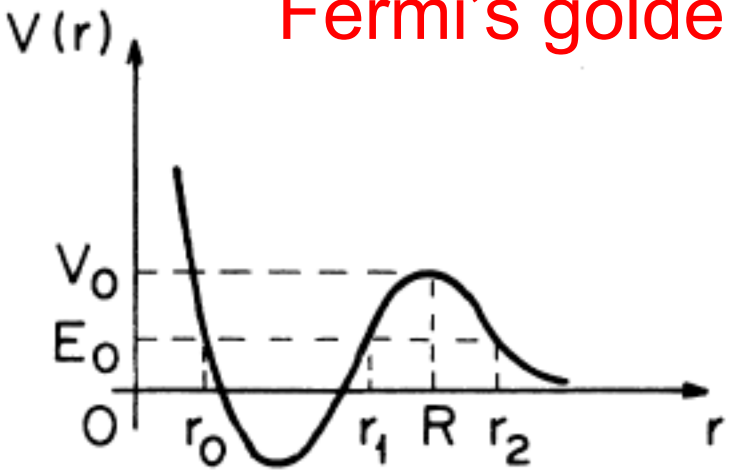


At t=0, alpha particle is localized inside the nucleus. It can be represented by a wave packet. At large times, the wave function is an outgoing wave.

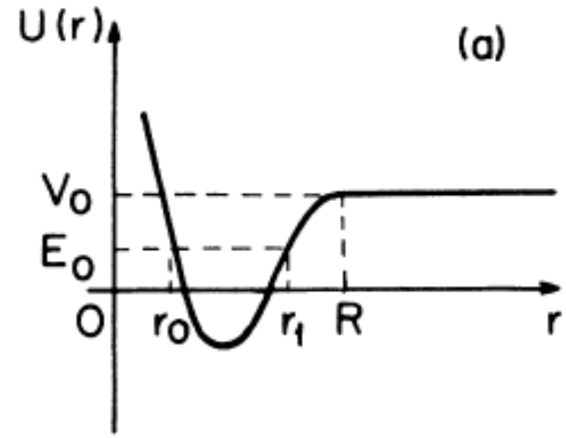
Two potential approach to tunneling

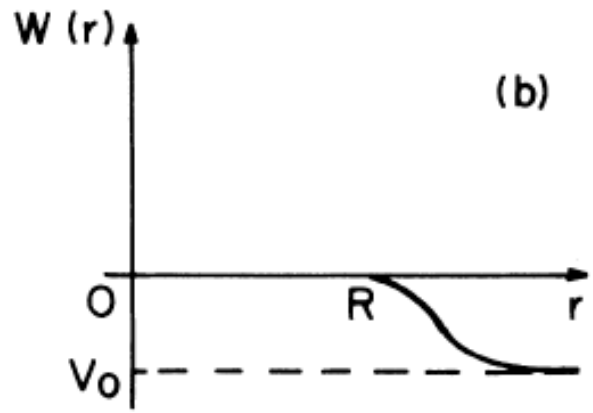
(decay width and shift of an isolated quasistationary state)

Phys. Rev. A 38, 1747 (1988); Phys. Rev. A69, 042705 (2004)



Fermi's golden rule!

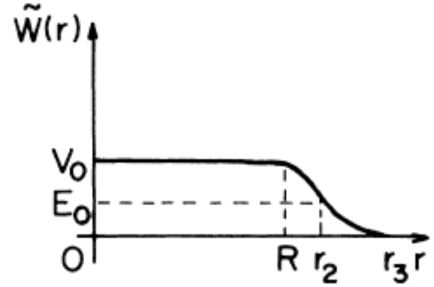


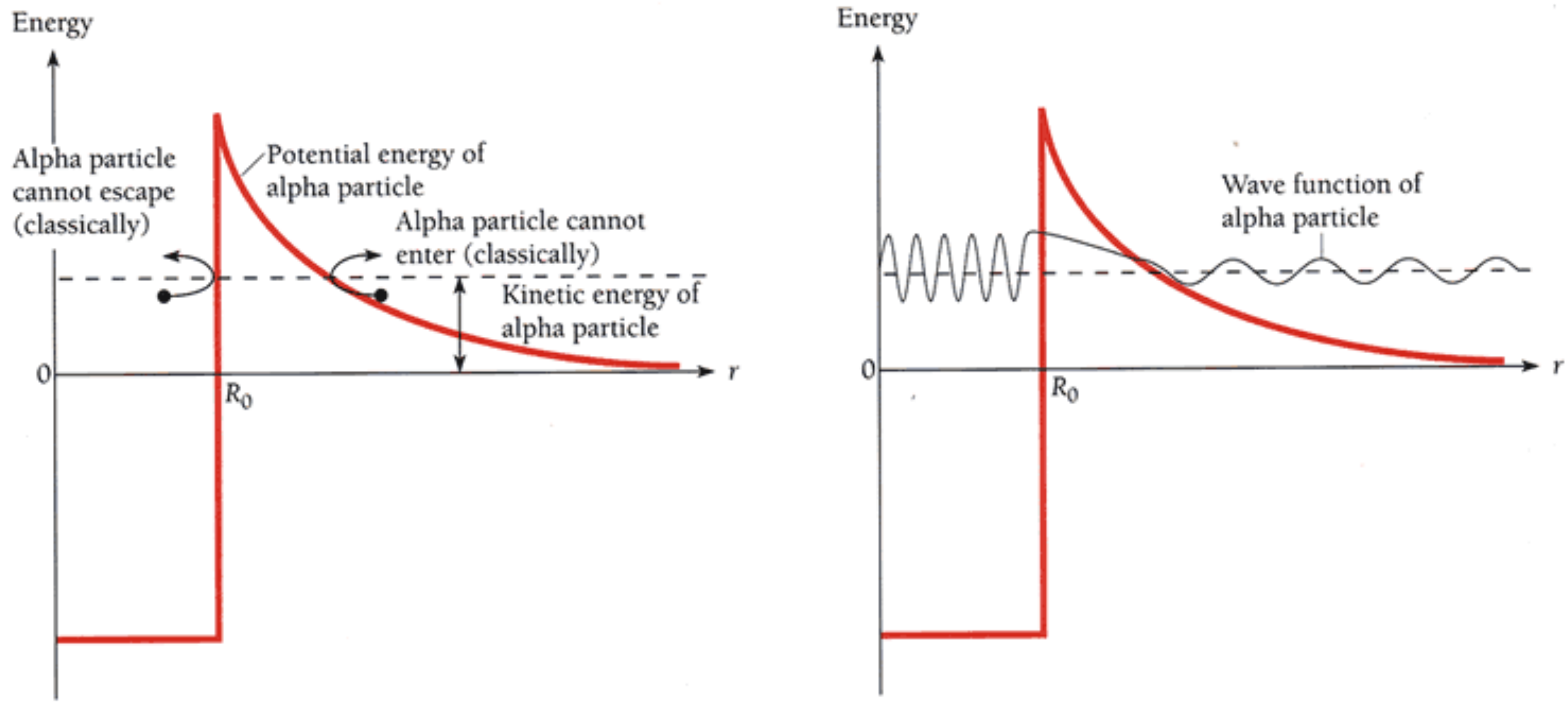


$$V(r) = U(r) + W(r)$$

open closed scattering

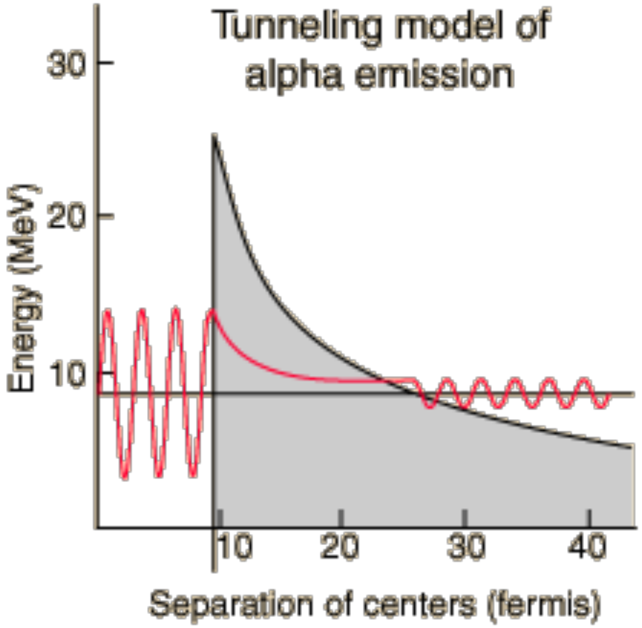
$$\tilde{W} = W + V_0$$





Energy
Alpha particle
cannot escape
(classically)
Potential energy of
alpha particle
Alpha particle cannot
enter (classically)
Kinetic energy of
alpha particle
0
R_0
r
Energy
Wave function of
alpha particle
0
R_0
r

$$P = \frac{|\chi_{III}|^2}{|\chi_I|^2} \propto \exp\left[-2\int_{r_1}^{r_2} k(r)\,dr\right] \qquad T \propto \frac{1}{P}$$



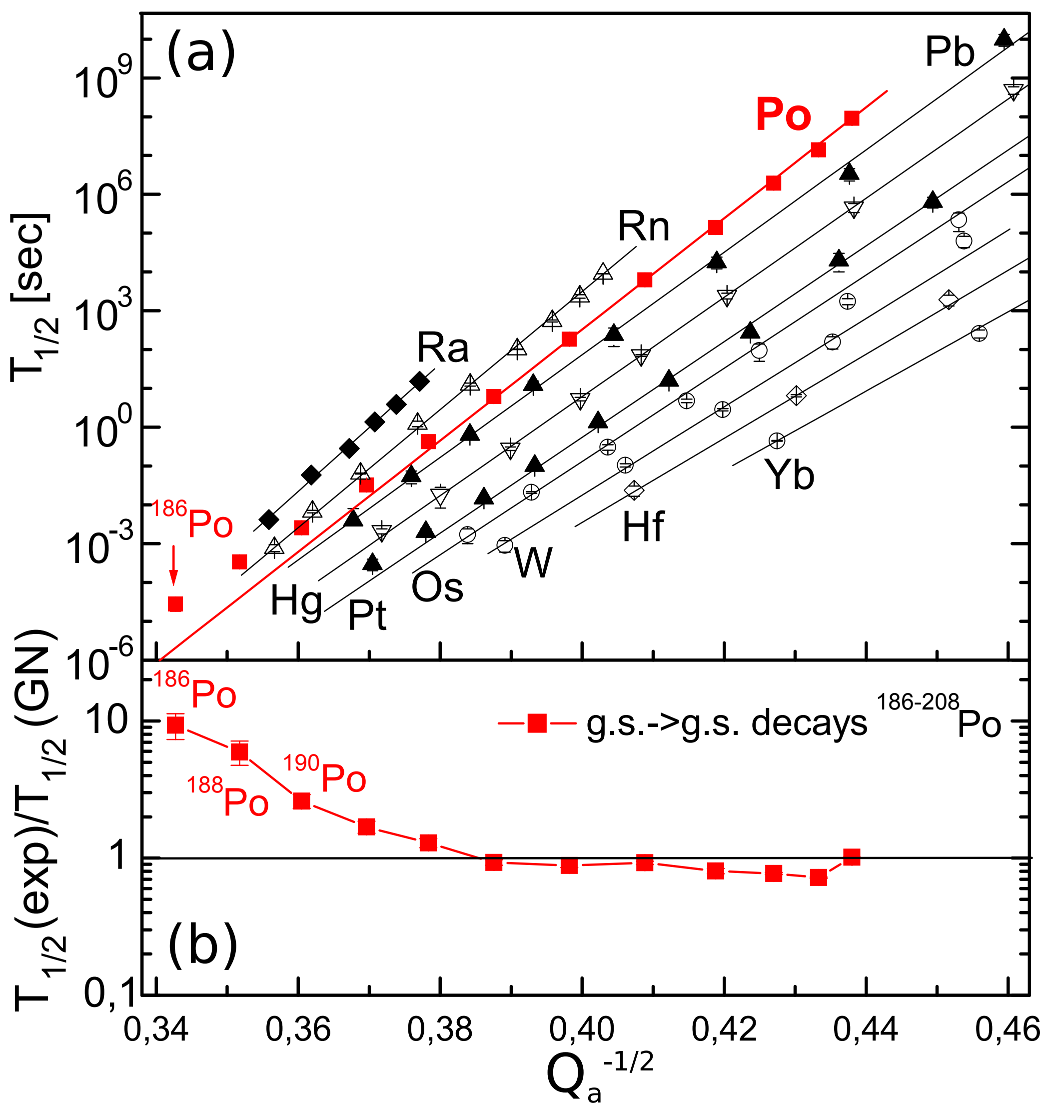
In the case of the Coulomb barrier, the above integral can be evaluated exactly.

$$\log T = a + \frac{b}{\sqrt{Q_\alpha}}$$

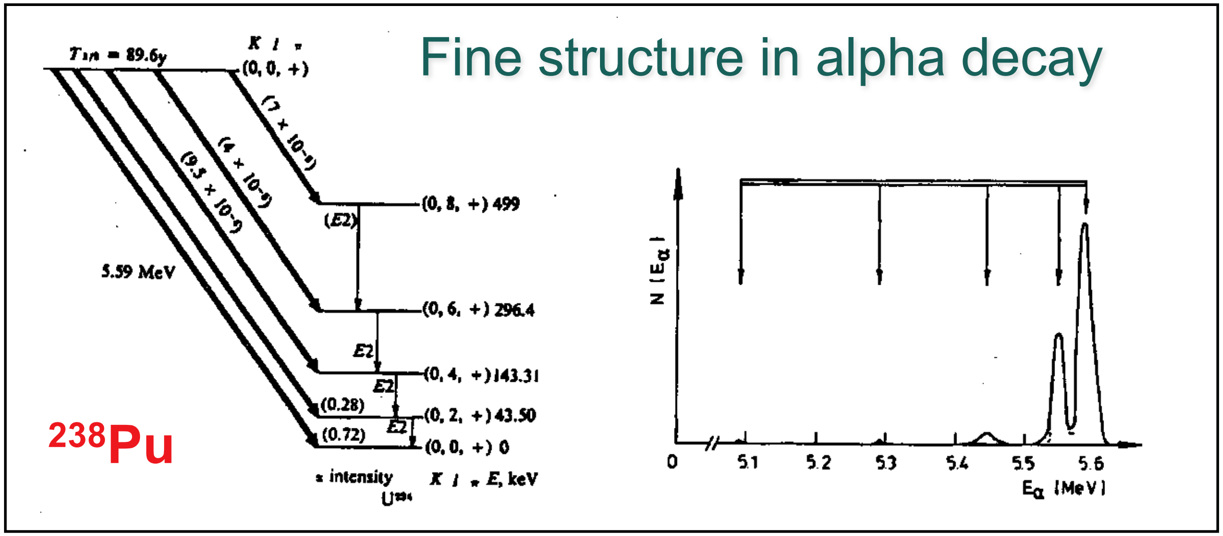
Geiger-Nuttall law of alpha decay 1911

XC: For the Coulomb barrier above, derive the Geiger-Nuttall law. Assume that the energy of an alpha particle is $E=Q_\alpha$, and that the outer turning point is much greater than the potential radius.

Phys. Lett. B 734 203 (2014)



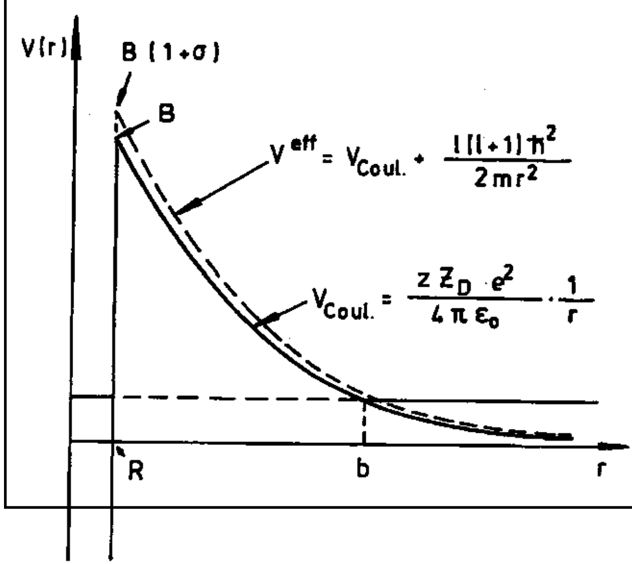
Fine structure in alpha decay



centrifugal barrier effect

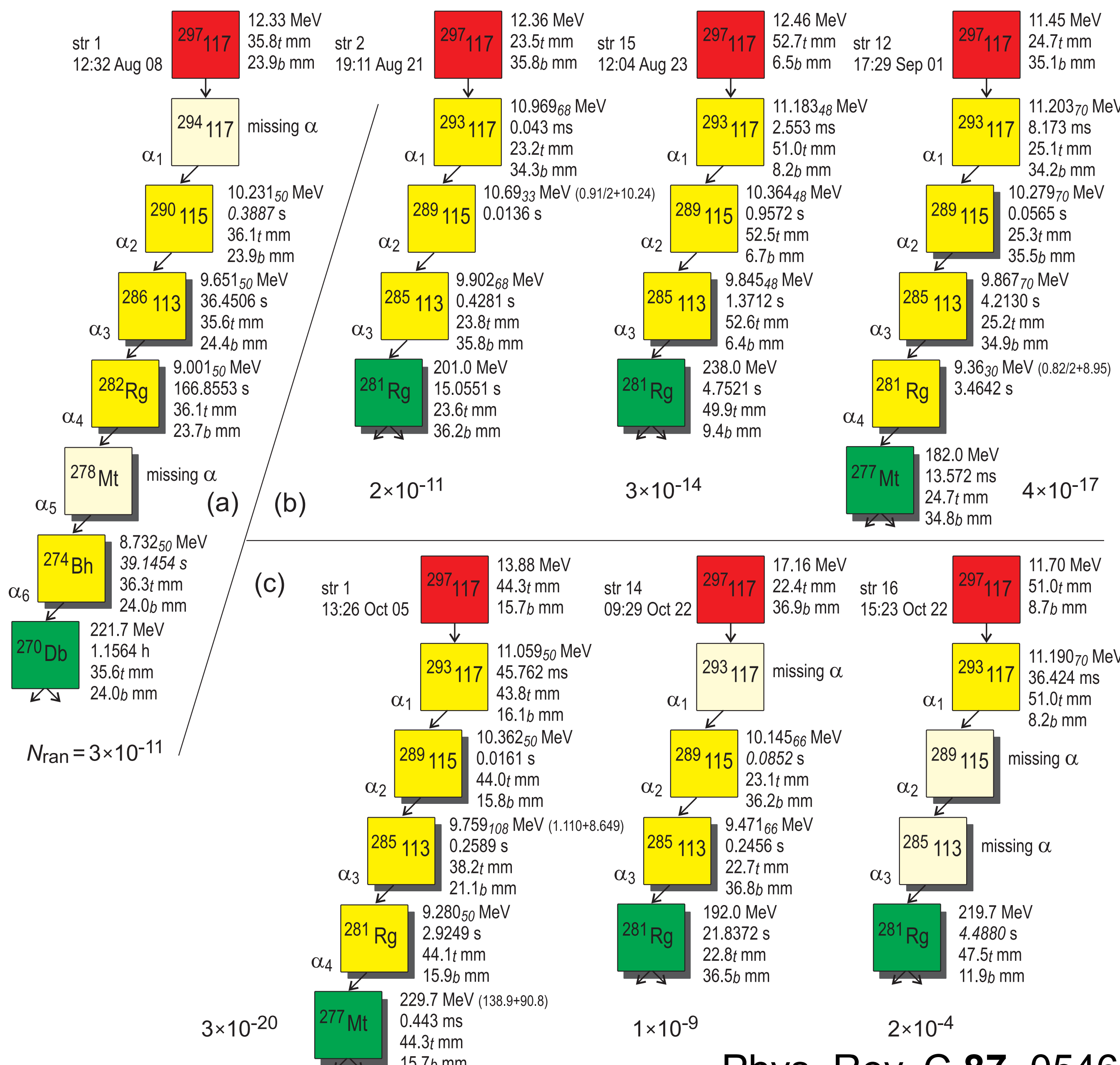
One still has to consider:

- alpha-particle formation
- angular momentum of alpha particle (centrifugal barrier effect)



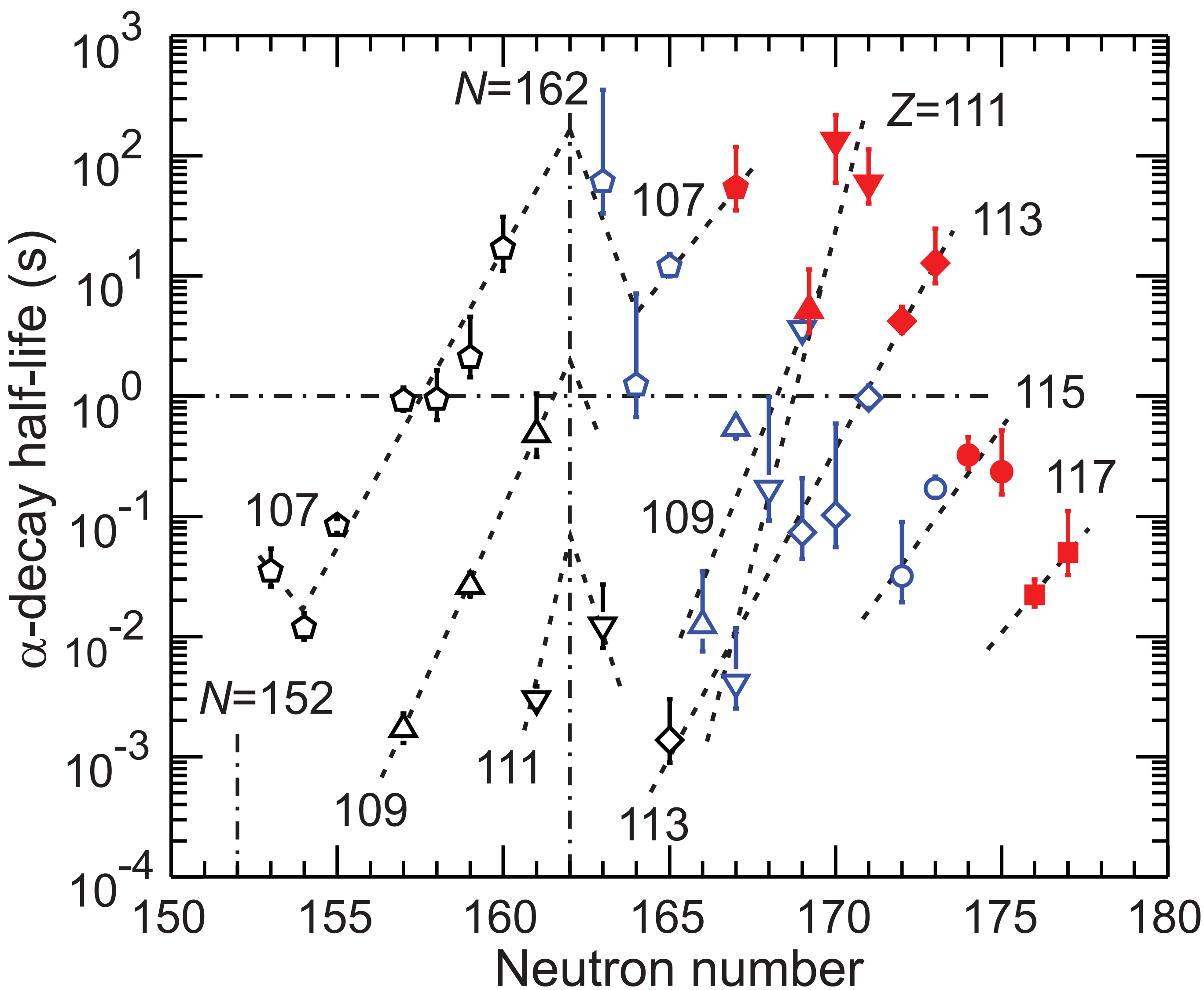
ℓ	$\frac{\lambda_\alpha(\ell)}{\lambda_\alpha(\ell=0)}$
0	1
1	0.7
2	0.37
3	0.137
4	0.037
5	7.1×10^{-3}
6	1.1×10^{-3}

Superheavy element alpha decays



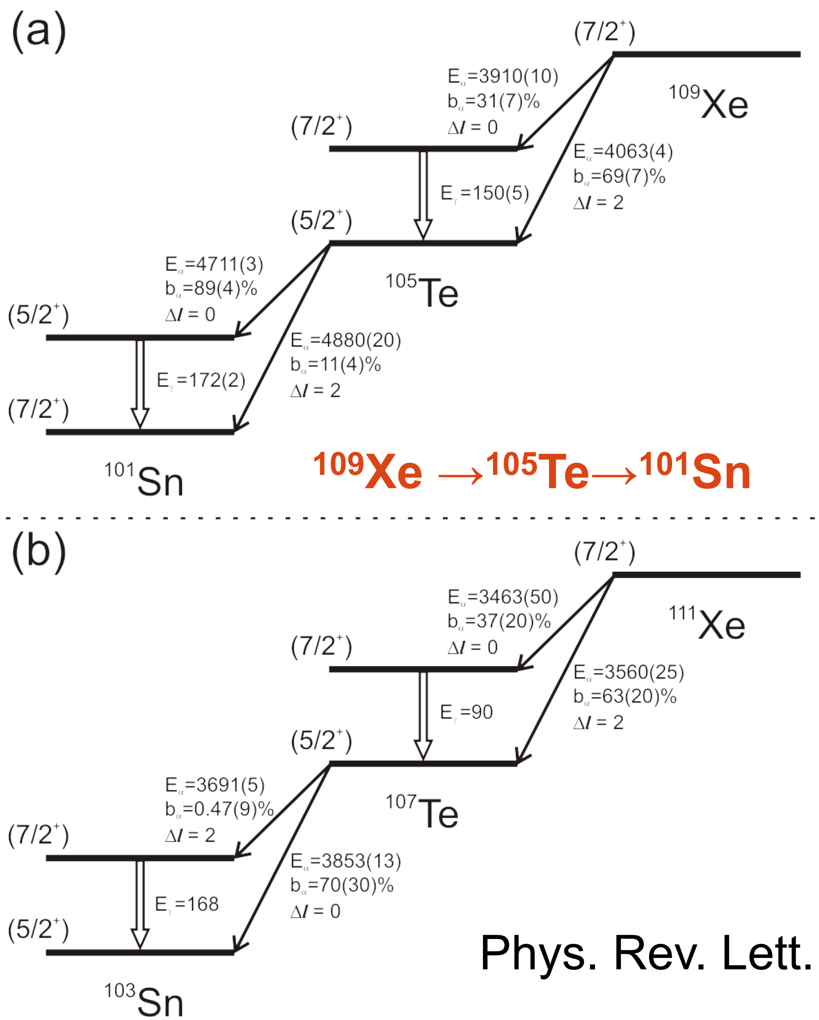
Phys. Rev. C **87**, 054621 (2013)

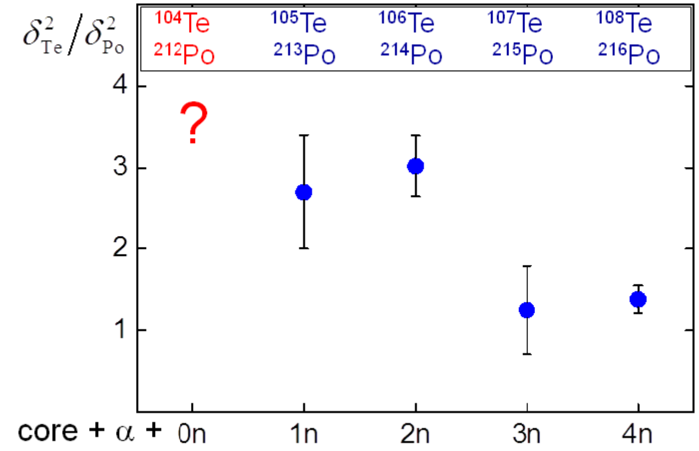
Superheavy element alpha decays



Phys. Rev. C **87**, 054621 (2013)

Superallowed alpha decays





The inversion of the ground-state spins between ^{103}Sn and ^{101}Sn is due to the strong pairing interaction between $g_{7/2}$ valence neutrons.

Phys. Rev. Lett. 105, 162502 (2010)