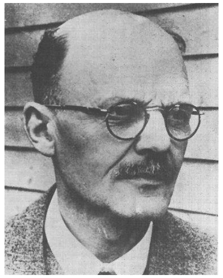
Geiger-Nuttall Rule (1911):

$$\ln \tau \propto \frac{1}{\sqrt{T_\alpha}}$$

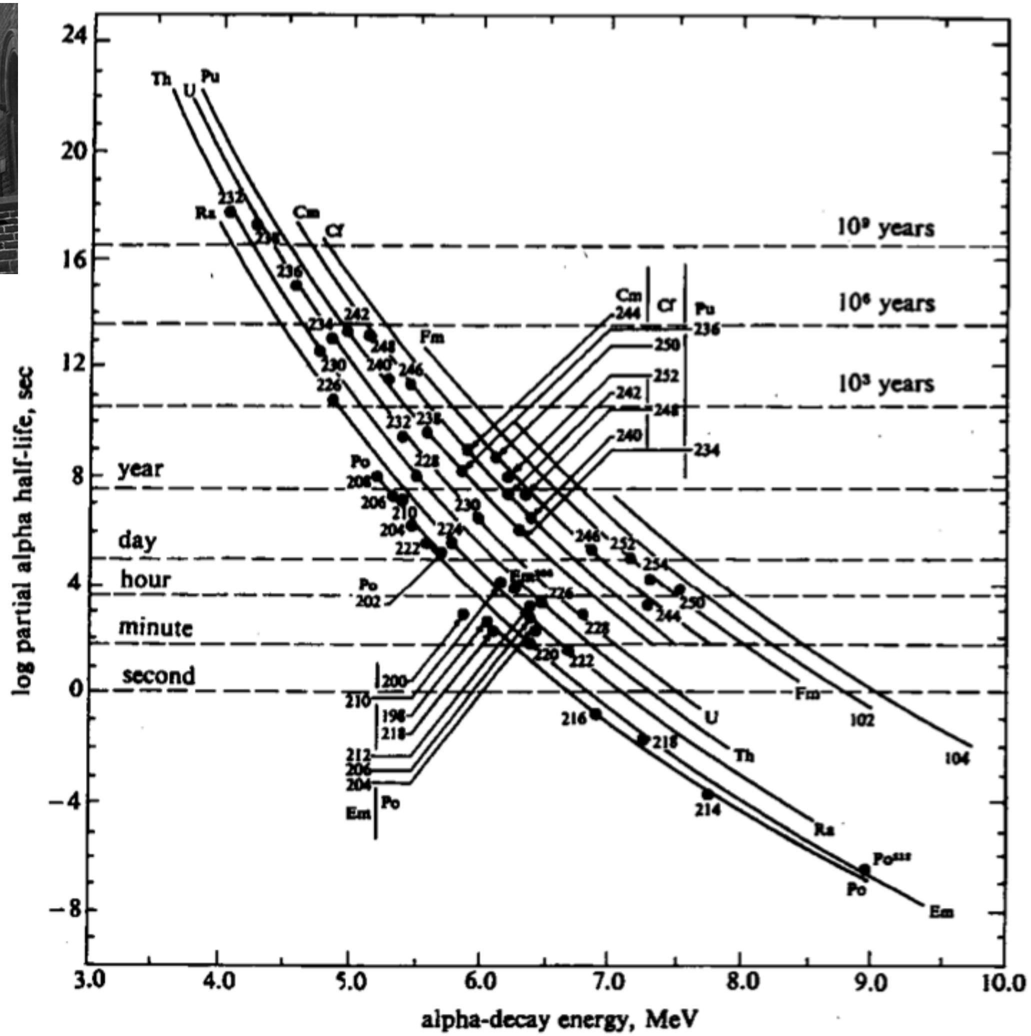
Huge variation in τ for little variation in decay energy, for example:

^{232}Th	1.4×10^{10} years	4 MeV
^{212}Po	10^{-7} seconds	9 MeV



$$^{228}_{90}\mathrm{Th} \rightarrow ^{224}_{88}\mathrm{Ra} + \alpha \quad Q \sim +5.5\ \mathrm{MeV}$$
$$^{228}_{90}\mathrm{Th} \rightarrow ^{227}_{89}\mathrm{Ac} + p \quad Q \sim -6.4\ \mathrm{MeV}$$

Highly excited states often have enough energy to offset this and weak binding can also alter things. Light particle emission is common at high excitation energy. Proton decay common near the proton drip line.



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Quantum Mechanical Tunnelling

Typical case, ^{228}Th, with α energy of 5.5 MeV.

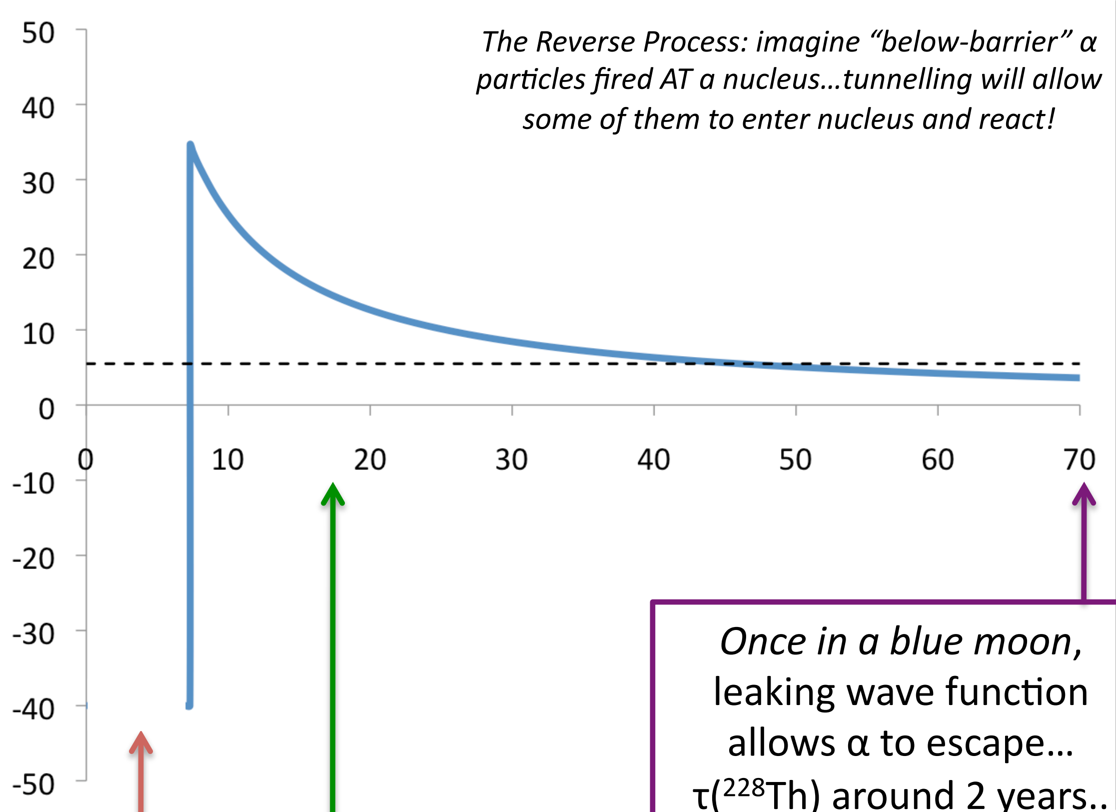
Take well depth ~200 MeV.
Radius $R=r_0A^{1/3}$= 7.3 fm

Coulomb Potential:

$$V_C(r) = \frac{1}{4\pi\epsilon_0}\frac{2Ze^2}{r}$$

α particle is below barrier from:
a=R=7.3 fm to b=50.6 fm

Show this!



α in nucleus with approx harmonic radial wave function KE approx. 200+5.5 = 205 MeV "Hits" barrier around 10^{22} times per second.

Show this!

Classically forbidden region: KE<V
Radial wave function rapidly decays away.

Once in a blue moon, leaking wave function allows α to escape… τ(^{228}Th) around 2 years.. ..so escapes after hitting barrier some 10^{30} times! Approx. harmonic wave function with longer wavelength than inside.

Show this!

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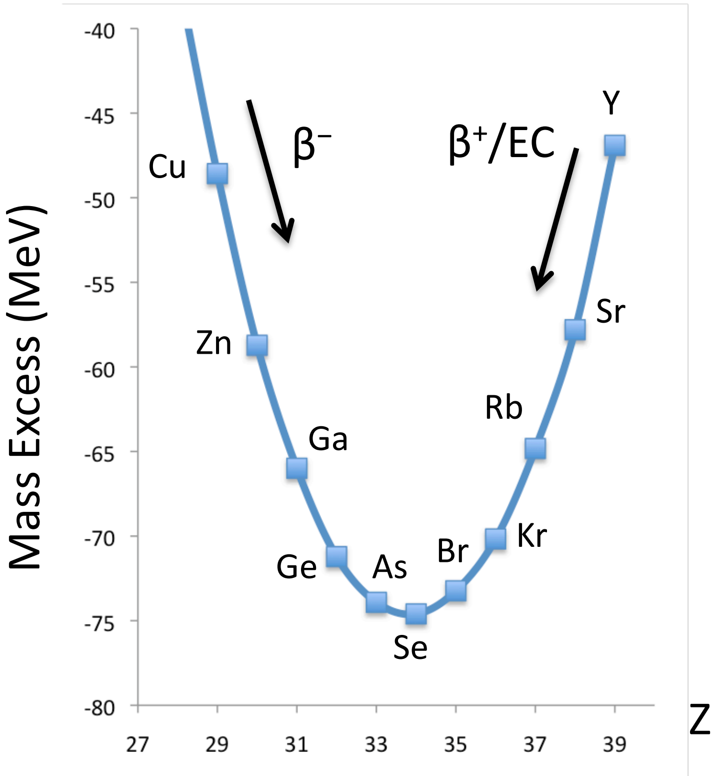
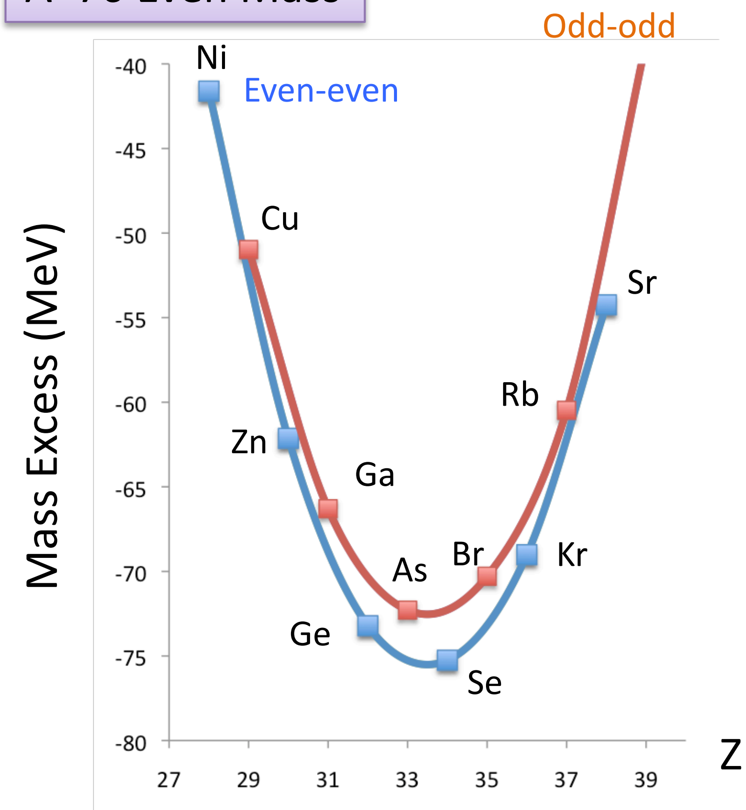
A=77 Odd Mass



A=76 Even Mass



$$M(A,Z) = ZM_{1H} + (A-Z)M_n - a_v A + a_s A^{2/3} + a_c \frac{Z^2}{A^{1/3}} + a_a \frac{(A-2Z)^2}{A} \mp \delta . A^{-1/2}$$

$$M(A,Z) = \alpha A - \beta Z + \gamma Z^2 + \frac{\delta}{A^{1/2}}$$

$$\alpha = M_n - a_v + a_s A^{-1/3} + \frac{a_a}{4}$$

$$\beta = a_a + M_n - M_H$$

$$\gamma = \frac{a_a}{A} + \frac{a_c}{A^{1/3}}$$

$\delta = a_p$

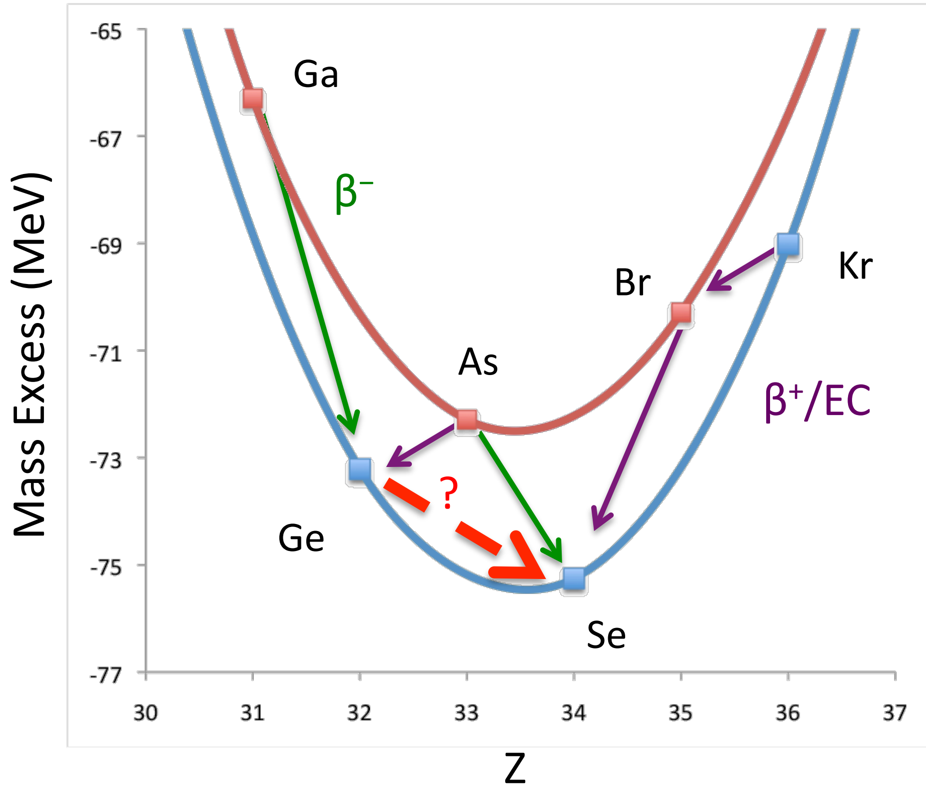
-11.2 MeV for even-even

0

+11.2 MeV for odd-odd

Double beta decay:

Example in A=76 Isobars:
Can ^{76}Ge decay to ^{76}Se?



Two-neutrino double beta decay:

$$^{76}\mathrm{Ge} \rightarrow {}^{76}\,\mathrm{Se} + 2e^- + 2\bar{\nu}$$

essentially two simultaneous normal β decays.
Measured with lifetimes of around 10^{21} years.

Neutrino-less double beta decay:

$$^{76}\mathrm{Ge} \rightarrow {}^{76}\,\mathrm{Se} + 2e^-$$

occurs if neutrinos are their own antiparticles!
(Probably) not been observed (yet)!
IF it occurs could be the only way to measure the absolute mass of the neutrino.
Lifetimes expected > 10^{25} years!

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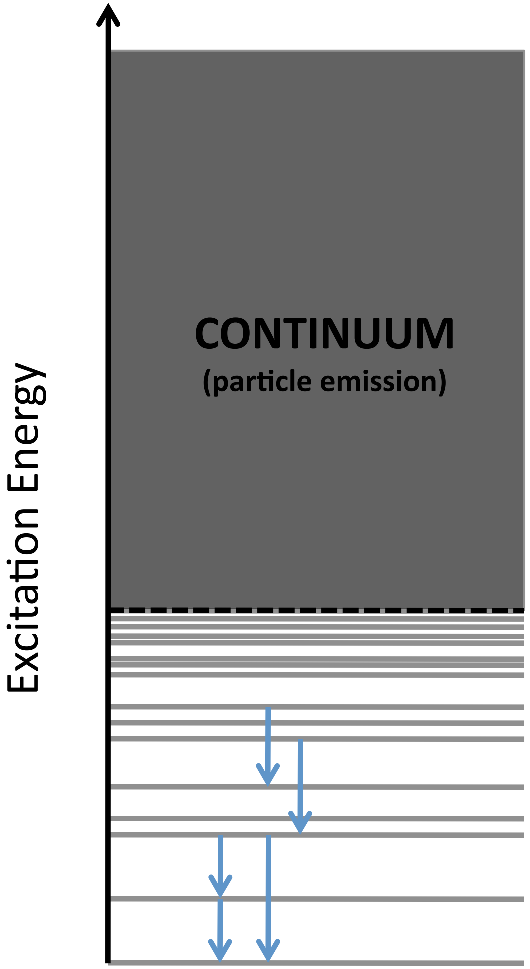

States above Sn can decay easily by particle emission. Short-lived so large widths. Level Density increases with excitation…continuum

Neutron separation energy

Discrete states with Γ< 1eV decay by gamma-ray emission.