Alpha Decay

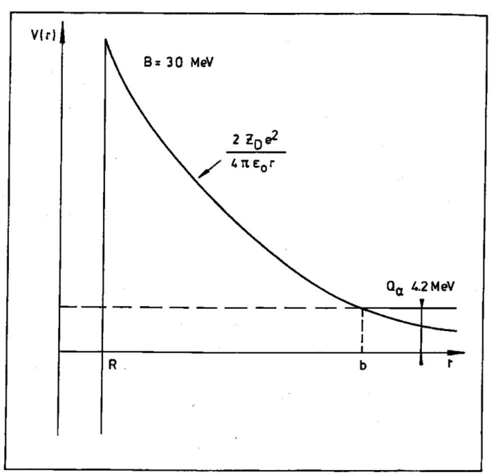
Theory of Alpha decay

$$\frac{|\chi_{III}|^2}{|\chi_I|^2} = \frac{1}{4}\left(1+\frac{q^2}{p^2}\right)\left(c_+^2 e^{G} + c_-^2 e^{-G}\right) + \frac{1}{2}\left(1-\frac{q^2}{p^2}\right)c_+c_-$$

When c_+=0, the penetrability becomes proportional to exp(-G), i.e.,

$$\frac{|\chi_{III}|^2}{|\chi_I|^2} \propto \exp\left[-\frac{2}{\hbar}\sqrt{2M(V_b - E)}(b-a)\right]$$

This is the semi-classical WKB result: $P = \frac{|\chi_{III}|^2}{|\chi_I|^2} \propto \exp\left[-2\int_{r_1}^{r_2} k(r)dr\right]$



In the case of the Coulomb barrier, the above integral can be evaluated exactly. The decay constant can be obtained by multiplying the probability of barrier penetration by a frequency of impacts on the barrier (v/R).

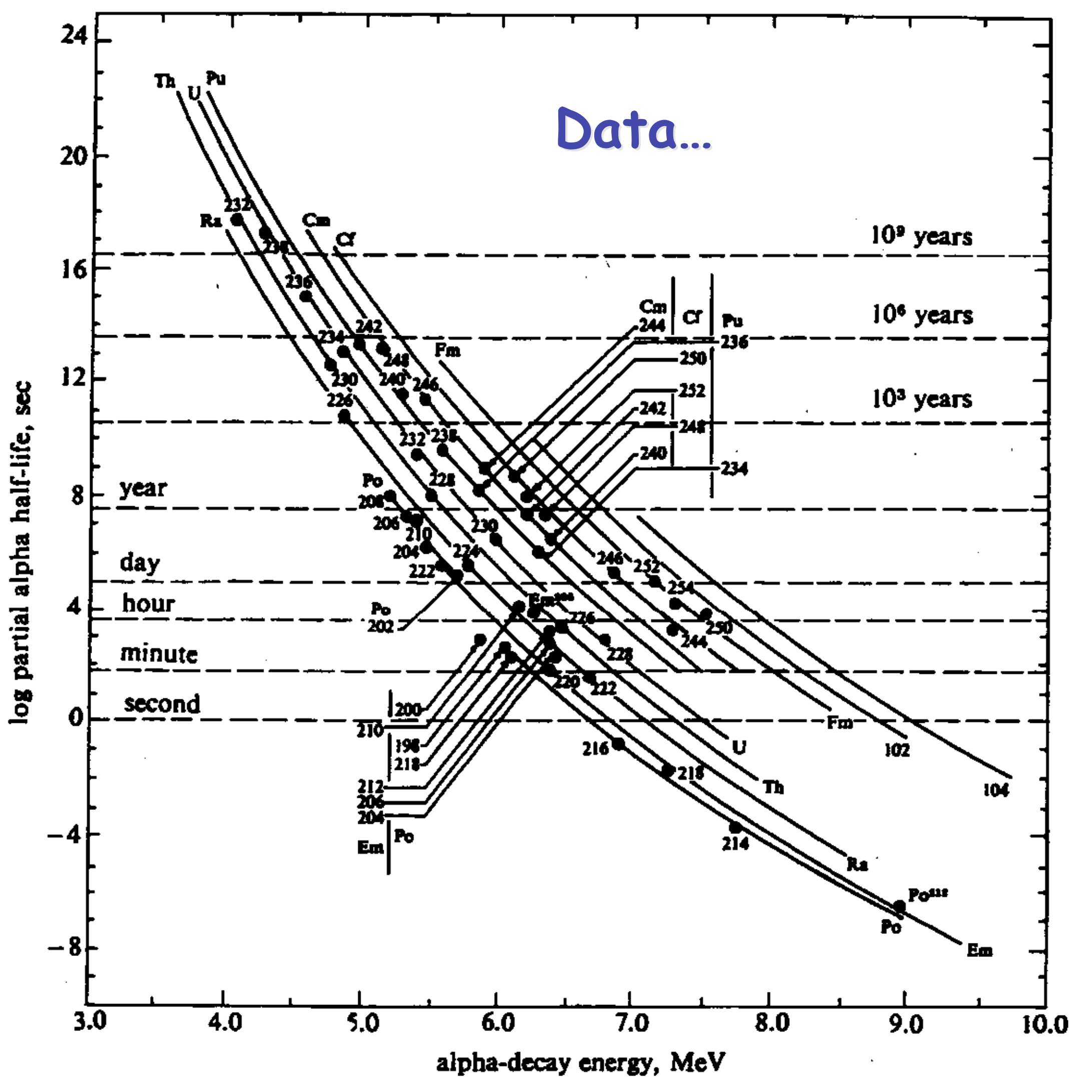
$$\lambda_\alpha = \frac{v}{R}\exp\left[-\frac{4\pi Z_D e^2}{\hbar v} + \frac{8e}{\hbar}\sqrt{Z_D M R}\right], \quad v = \sqrt{2Q_\alpha / M}$$

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

Geiger-Nutall law of alpha decay 1911

Alpha Decay

Theory of Alpha decay



One still has to consider:

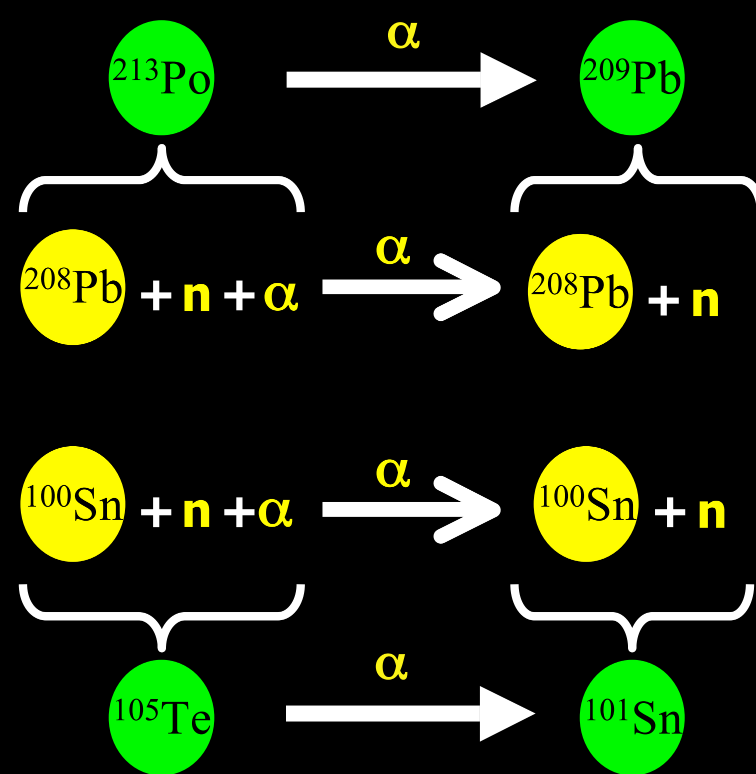
- preformation process
- angular momentum of alpha particle (centrifugal barrier effects)

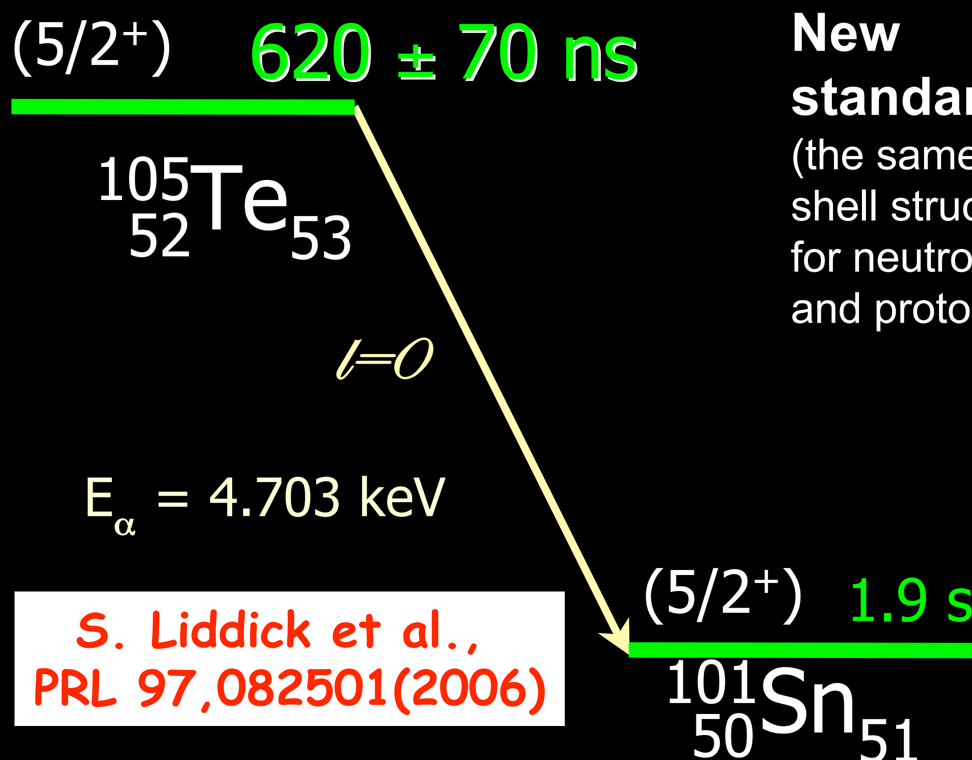
Superallowed α-decay $^{109}Xe \rightarrow {}^{105}Te \rightarrow {}^{101}Sn$

- rp-process termination
- en route to $^{104}Te \rightarrow {}^{100}Sn$

Old standard (different shell structure for neutrons and protons)

New standard (the same shell structure for neutrons and protons)





S. Liddick et al., PRL 97,082501(2006)

Identification at HRIBF of fastest known alpha decays:

$\delta^2(^{105}Te)/\delta^2(^{213}Po) = 2.4(3)$

Identification of some of the fastest known α-decays at HRIBF

Alpha decay, i.e., emission of alpha particle by a nucleus, is one of the oldest nuclear decay modes known. Due to large electrostatic repulsion, alpha emission is, together with fission, the dominant decay mode in the heavy elements above ^{208}Pb, a "double-magic" nucleus that has a particular number of protons and neutrons. These traditional heavy alpha emitters have the number of neutrons significantly greater than the proton number. Interestingly, it has been postulated over 40 years ago that by far the fastest alpha decays should occur in medium-mass nuclei just above the short-lived, double-magic ^{100}Sn having nearly equal numbers of protons and neutrons. This is because just in these nuclei the alpha particle (two protons and two neutrons clustered together) can form much easier. The region of nuclei above ^{100}Sn is also particularly interesting since very fast alpha and proton decays are expected to terminate the astrophysical rp-process, the rapid sequence of proton captures and beta decays contributing to the formation of heavy nuclei in hot stars.

The road to super-fast (or, superallowed) alpha emitters is not easy. Because these nuclei have abnormally few neutrons, their life span lasts for less than 0.000001 (1 micro-) second. To probe such elusive nuclear species, experimentalists had to resort to the advanced digital signal processing technique. This novel method was necessary to identify the events formed by signals of two alpha decays spaced closely in time. The sub-microsecond alpha decay chain $^{109}Xe \rightarrow {}^{105}Te \rightarrow {}^{101}Sn$ studied at the HRIBF's Recoil Mass Spectrometer turned out be about three times faster than the alpha emissions above ^{208}Pb, see Liddick et al., Physical Review Letters 97, 082501 (2006). The hunt for the super-fast alpha-decays is not over. The speediest one should be from ^{104}Te to ^{100}Sn, a "holy grail" of nuclear structure physics. The collaboration promises that the current world record held by ^{105}Te won't last long!

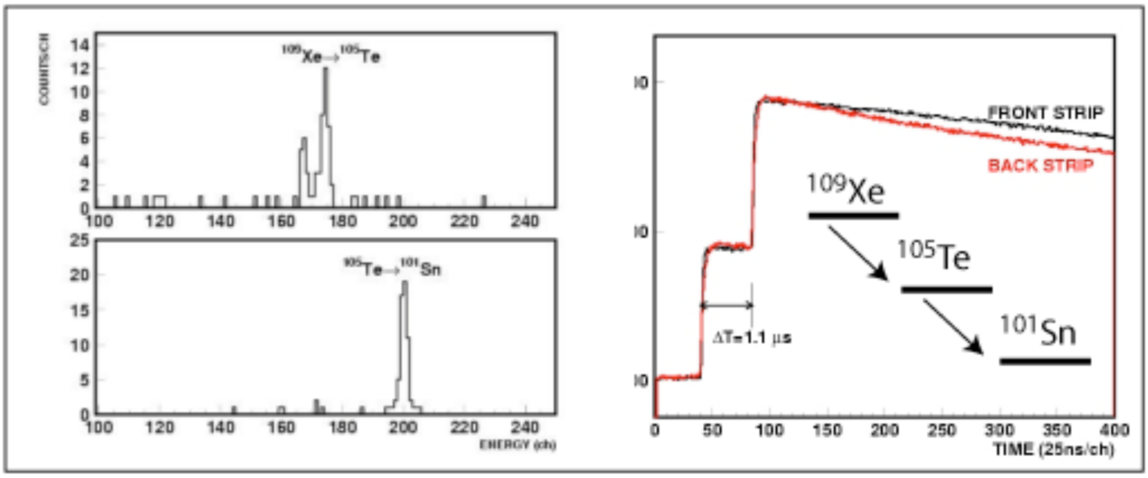
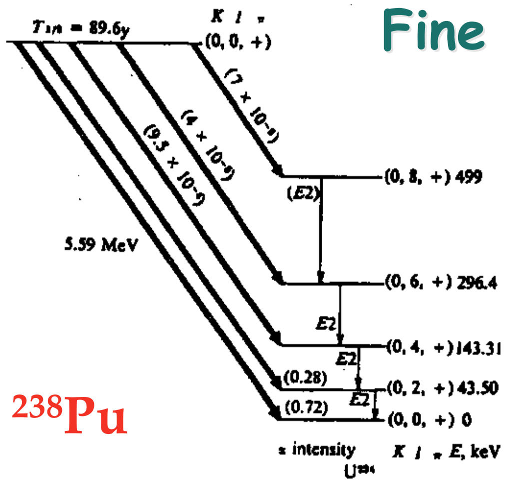


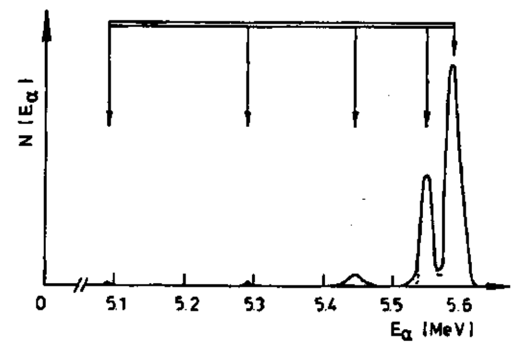
Fig.1. Experimental evidence for the super-fast alpha decays. The left panel shows the energy spectrum of alpha particles emitted from ^{109}Xe (halflife $T_{1/2}$=13 ms) and ^{105}Te ($T_{1/2}$=620 ns). The analysis of recorded traces of double-alpha pulses is displayed in the right panel. The two lines in ^{109}Xe indicate the decay to the ground and first excited state in ^{105}Te. The single line in the ^{105}Te spectrum corresponds to the superallowed alpha decay to the ground state of ^{101}Sn.

Alpha Decay

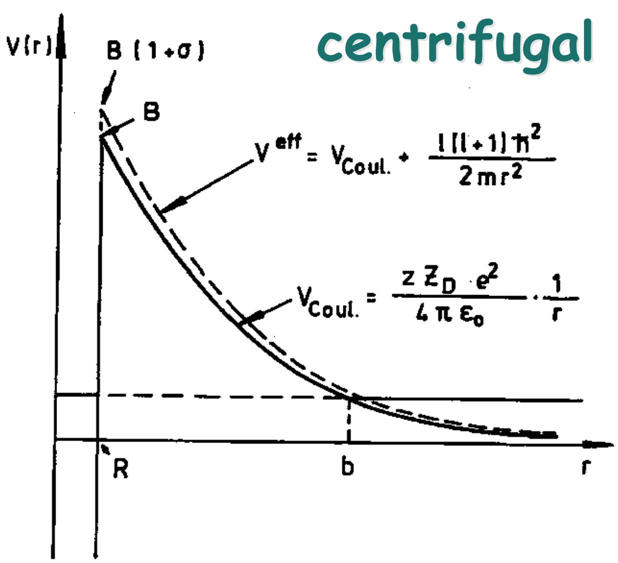
Theory of Alpha decay

Fine structure in alpha decay





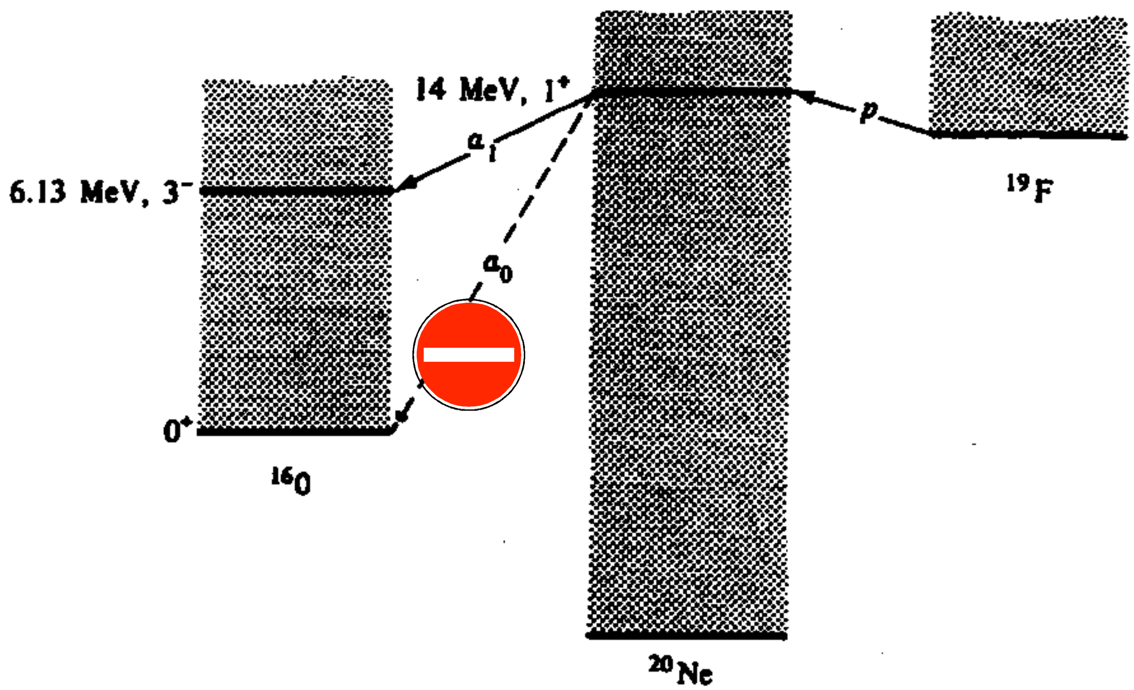
centrifugal barrier effect



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}

Alpha Decay

Parity violation in strong (alpha) decay



$$\pi_i = \pi_f (-1)^{\ell}$$

Experimental limit (1991) for parity breaking in this case is 10^{-13}
(strong interactions conserve parity!)