Lesson 7

Alpha Decay
Alpha decay ($\alpha$)

- Decay by the emission of doubly charged helium nuclei $^4\text{He}^{2+}$.
- $^{238}\text{U} \rightarrow ^{234}\text{Th} + ^4\text{He}$
- $\Delta Z = -2$, $\Delta N=-2$, $\Delta A=-4$
- All nuclei with $Z \geq 83$ decay by $\alpha$-decay as do some rare earth nuclei. Alpha decay is also known in the $^{100}\text{Sn}$ region.
Alpha Decay

- The emitted $\alpha$-particles are monoenergetic, ranging in energy from 1.8-11.6 MeV (typically 4-9 MeV).
- They can be stopped by a piece of paper and are thus an internal radiation hazard rather than an external hazard.
- The naturally occurring $\alpha$-emitters form long series of nuclei that decay to one another. Some of these naturally occurring decays series involve isotopes of Rn, a gas.
Important Features of Alpha Decay

• Generally energy of decay increases with increasing Z, but in any case the energy of the emitted $\alpha$-particle is less than the Coulomb barrier for the $\alpha$-nucleus interaction.

• For e-e nuclei, decay leads to gs of daughter. For odd A nuclei, decay is not to the gs but a low-lying excited state.
Energetics of Alpha Decay

• $Q_{\text{alpha}}$
Energetics of Alpha Decay (cont.)

- $Q_{\text{alpha}}$ -- Generally increases with increasing $Z$, but is subject to shell effects.

$Z=82$, $N=126$  \hspace{2cm} \text{versus} \hspace{2cm} N=152-154$
\[ Q_\alpha, \ T_\alpha \]

\[ Q_\alpha = (M_{\text{parent}} - M_{\text{daughter}} - M_{\text{alpha}})c^2 \]

\[ T_\alpha = Q_\alpha \frac{M_{\text{daughter}}}{M_{\text{parent}}} \]

\[ T_{\text{recoil}} = Q_\alpha \frac{M_{\text{alpha}}}{M_{\text{parent}}} \]

Difference between detecting emitted alpha particle and detecting alpha from implanted atom.
Closed decay cycles

Used to measure unknown masses or Q values for beta decay
Understanding natural alpha-decay chains

- In the U natural decay series, see pattern of mixed alpha and beta decays. Why?
Understanding Alpha Decay

- The problem:
Understanding Alpha Decay (cont.)

• The Geiger Nuttall Law

\[ \log(t_{1/2}) = A + \frac{B}{\sqrt{Q_\alpha}} \]
Theory of Alpha Decay

- One of the first successes of quantum mechanics
\[ \lambda = fT \]
\[ f = \frac{\mathbf{v}}{2R} = \frac{\sqrt{2(V_0 + Q)/\mu}}{2R} \sim 10^{21} / s \]
\[ T \approx e^{-2G} \]
\[ 2G = \frac{2}{\hbar} \int_{x_1}^{x_2} \left[ 2m(V(x) - E) \right]^{1/2} dx \]
\[ 2G = \frac{2}{\hbar} \int_{R}^{b} \left[ 2\mu \left( \frac{Z_\alpha Z De^2}{r} - Q_\alpha \right) \right]^{1/2} dr \]
\[ b = \frac{Z_\alpha Z De^2}{Q_\alpha} \]
After some algebra and simplifying for the nuclear case

$$2G = 2\sqrt{\frac{2\mu}{\hbar^2 Q_\alpha}} (Z\alpha Z_D e^2) \left(\frac{\pi}{2}\right) \sim 60 - 120$$

$$T \sim 10^{-55} - 10^{-27}$$

Then

$$t_{1/2} = \frac{\ln 2}{\lambda} = \frac{\ln 2}{fT} = \frac{\ln 2}{\left[\frac{2(V_0 + Q_\alpha)/\mu}{2R}\right]^{1/2} e^{-2G}}$$

This is called the “one-body” theory of alpha decay.
How well does one-body theory work?

Role of "pre-formation factor"
Effect of angular momentum

Selection Rules
Which states of daughter are populated in alpha decay?

- Dominant effect is $Q_\alpha$
- Angular momentum effect

Angular momentum = $\ell$

Parity = (-1)
Hindrance Factors

Hindrance Factor = $t_{1/2}(\text{meas})/t_{1/2}(\text{one-body})$
Proton Decay

- Same theory as alpha decay, except no pre-formation factor for protons
- Where do you expect to see proton decay? ($S_p=0$)
Proton Decay (cont.)

- Proton energies are low and transmission factors are small.
Proton Decay (cont.)

- Alpha decay complicates measurements
Heavy Particle Decay

- What about emitting particles other than alphas or protons?

\( Q_{12c} \)