Week 5 Lecture 3 – Beta Decay

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Decay Processes

-- Alpha Decay revisited

-- Beta Decay revisited

--- Decay chains

--- Fermi function

--- Half-lives, log *ft*

4th Homework
due Monday

Beta Decay – Basic Equations

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$${}^{14}_{6}C \rightarrow {}^{14}_{7}N^{1+} + e^- + \bar{\upsilon}_e + Q_{\beta -} \qquad Q_{\beta -} = \Delta({}^{14}_{6}C) - \Delta({}^{14}_{6}N)$$

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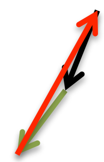

$${}^{14}_{8}O \rightarrow {}^{14}_{7}N^{1-} + e^+ + \upsilon_e + Q_{\beta +} \qquad Q_{\beta +} = \Delta({}^{14}_{8}O) - \Delta({}^{14}_{6}N) - 2m_e e^2$$

$$or \quad {}^{14}_{8}O \rightarrow {}^{14}_{7}N + e^- + e^+ + \upsilon_e + Q_{\beta +}$$

β - decay: Electron & antineutrino are created

β + decay: antielectron & neutrino are created

β^+ Alternative in heavy nuclei and when $Q_{\beta+} < 2m_e c^2$ is Electron Capture decay : electron is destroyed & neutrino is created

Q: What about positron capture decay as an alternative to β^- decay?

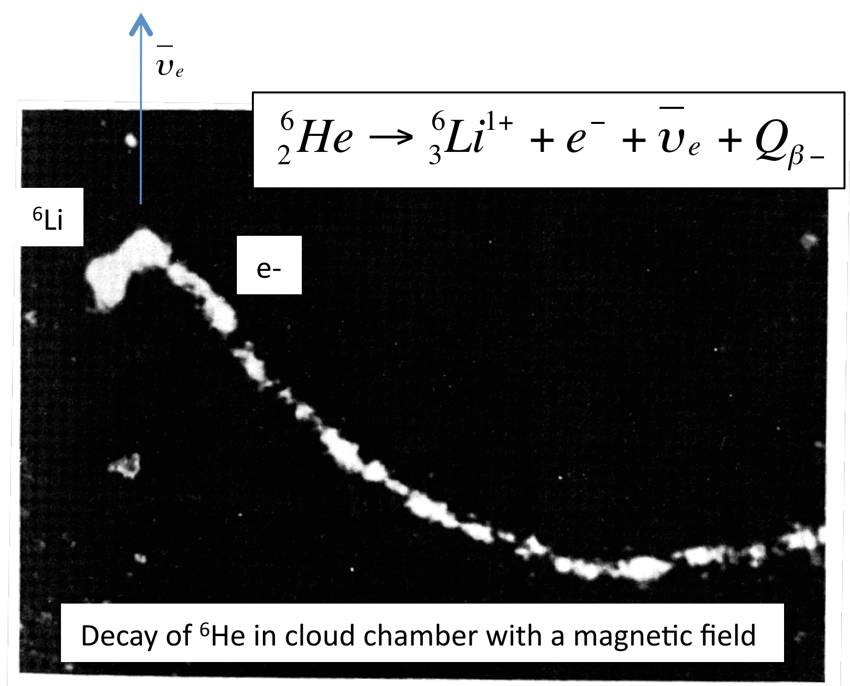

Figure 9-2 Recoil of ^{6}He in beta decay. [J. Csikay and A. Szalay, *Nuovo Cimento, Suppl.*, Padova Conference, 1957.]

From: *Nuclei and Particles, 2nd Ed.* by E. Segre

Beta Decay – Decay Chains

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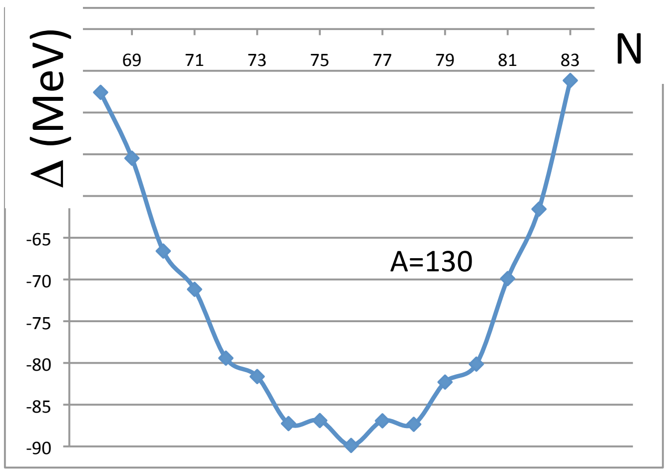
Recall that beta decay does not change the number of nucleons (i.e., baryons). Thus if one creates an unstable nucleus that has an excess of either protons or neutrons it will decay by a series of beta decays until it reaches the stable isobar for that mass number.

Sometimes there are problems for nuclei with even mass numbers near the bottom of the mass parabola. For example, consider the A=130 isobars.



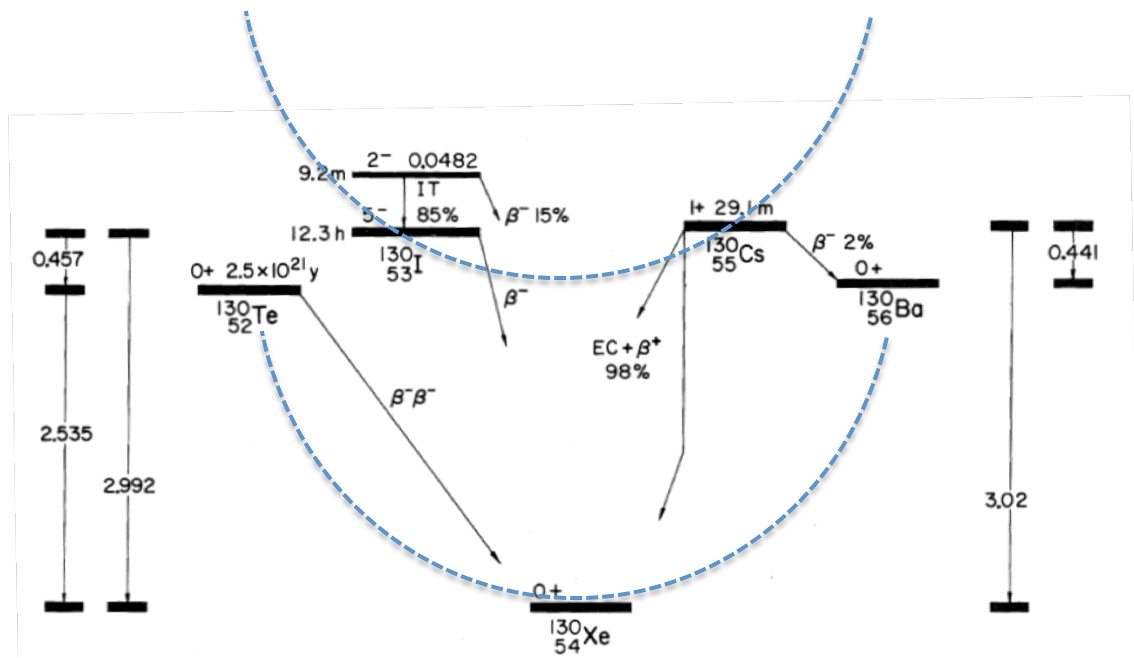


Figure 9-7 Level diagram for double beta decay of ^{130}Te. Energy scales in MeV.

Beta Spectra – Fermi Function – 1

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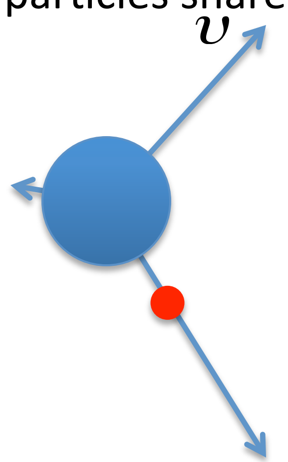
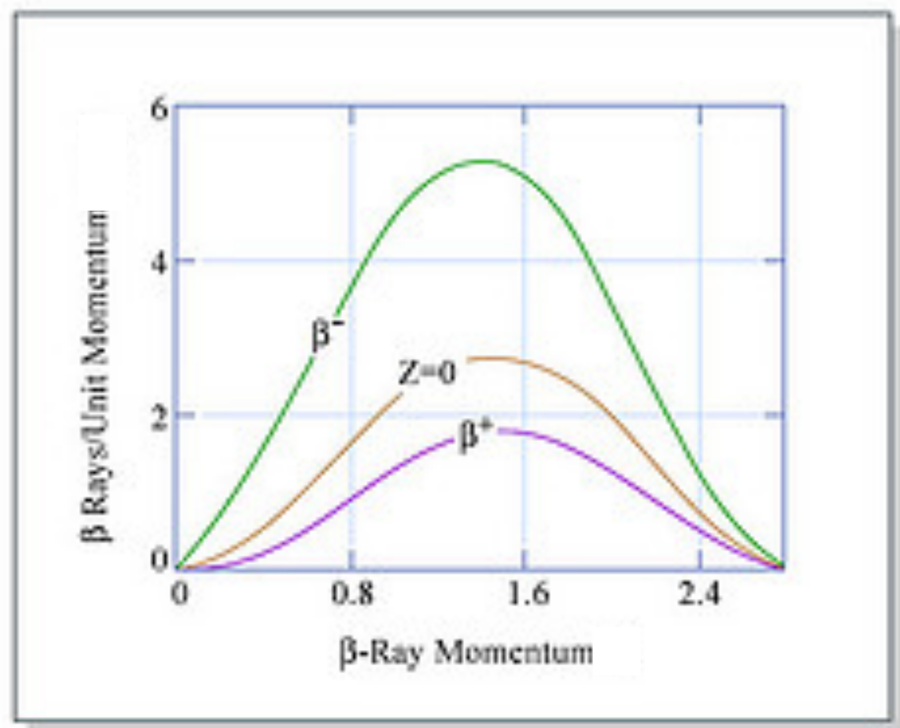
The decay energies are on the order of a MeV's and the energy is shared among the three particles (electron, neutrino, and recoiling nucleus). Three particles can each take any amount of kinetic energy from zero all the way up to Q_β.
[Recall if two particles share the kinetic energy they get only one exact fraction of that energy.]



The governing principles are conservation of momentum and energy. Concentrating on the electron (easiest to observe and measure) we have a function that must be zero at mv = 0 and also when the electron KE = Q_β

The general shape of this curve is given by the a mathematical expression called the Fermi function, F(Z_D, p).



Similar to Fig. 8-1 in the text

Beta Spectra – Fermi Function – 2

$$^{64}_{29}Cu_{35} \rightarrow {}^{64}_{30}Zn^{1+} + e^{-} + \overline{\upsilon}_e + Q_{\beta-} \quad 61\%$$

$$\rightarrow {}^{64}_{28}Ni^{1-} + e^{+} + \upsilon_e + Q_{\beta+} \quad 39\%$$

Recall that the electron mass is 9.11x10^{-31} kg which converts to 0.511 MeV. Thus, the electrons have to be treated relativistically.

$$E_{Total} = m_o c^2 + T$$

$$E_{Total}^2 = (m_o c^2)^2 + (pc)^2$$

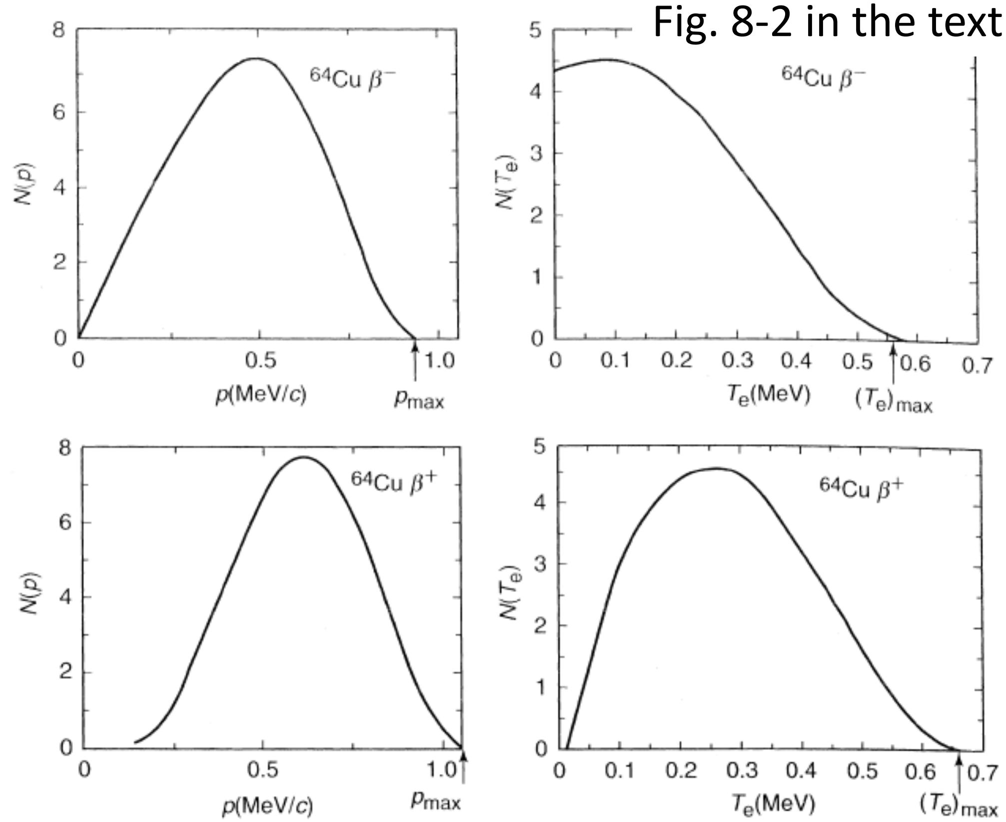
$$(m_o c^2)^2 + 2m_o c^2 T + T^2 = (m_o c^2)^2 + (pc)^2$$

$$2m_o c^2 T + T^2 = (pc)^2$$

$$\sqrt{2m_o c^2 T + T^2} = pc$$

$$\sqrt{2m_o T + \frac{T^2}{c^2}} = p$$

Fig. 8-2 in the text



Beta Half-lives – Log *ft*

The general form of the decay constant for beta decay was derived by Enrico Fermi and is outlined in the text. The most important components of the derivation include:
(1) an integral over the Fermi function, F(Z_D, p) and electron momentum which is called the Fermi integral, f(Z_D, Q_β)
(2) a representation of the matching of the initial nuclear wavefunction with the final nuclear wavefunction called the nuclear matrix element, M_{if}.

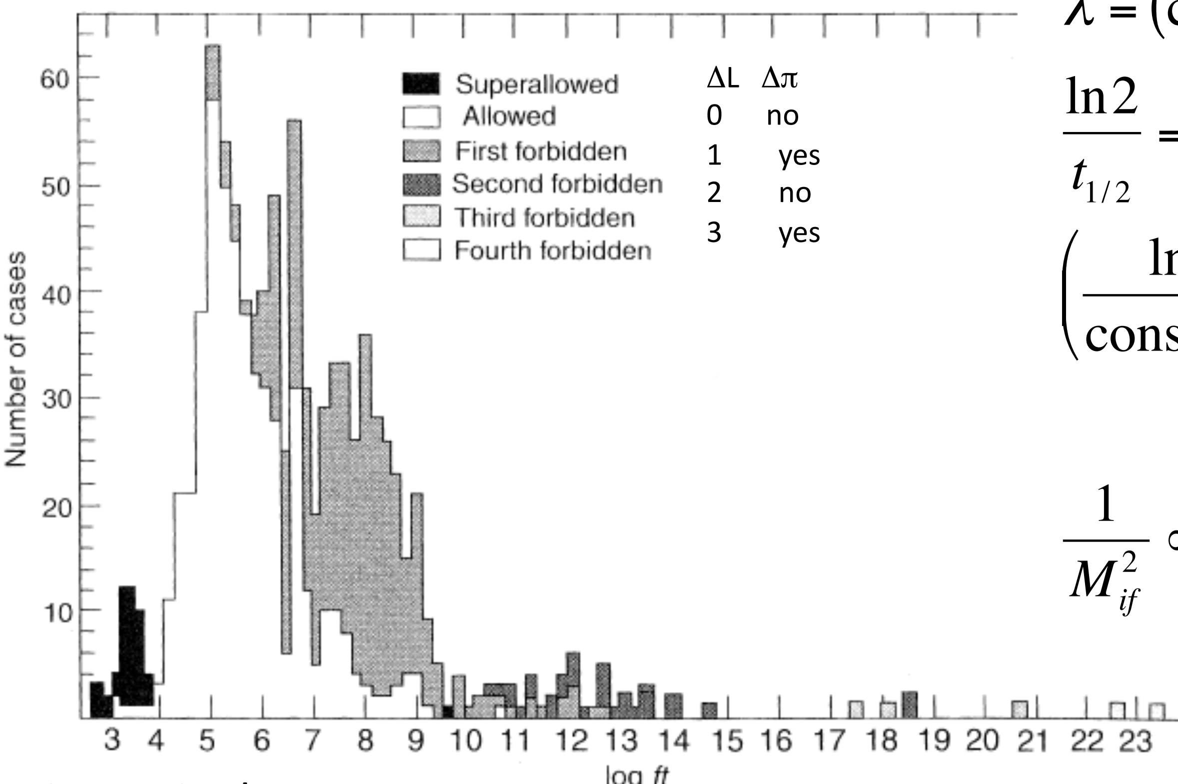


Fig. 8-5 in the text

$$\lambda = (\text{constants}) M_{if}^2 f(Z_D, Q_\beta)$$

$$\frac{\ln 2}{t_{1/2}} = (\text{constants}) M_{if}^2 f(Z_D, Q_\beta)$$

$$\left(\frac{\ln 2}{\text{constants}}\right) \frac{1}{M_{if}^2} = f(Z_D, Q_\beta) t_{1/2}$$

$$\frac{1}{M_{if}^2} \propto f t_{1/2}$$