THE "CLASSICAL" EXPERIMENTAL TESTS OF THE FERMI THEORY

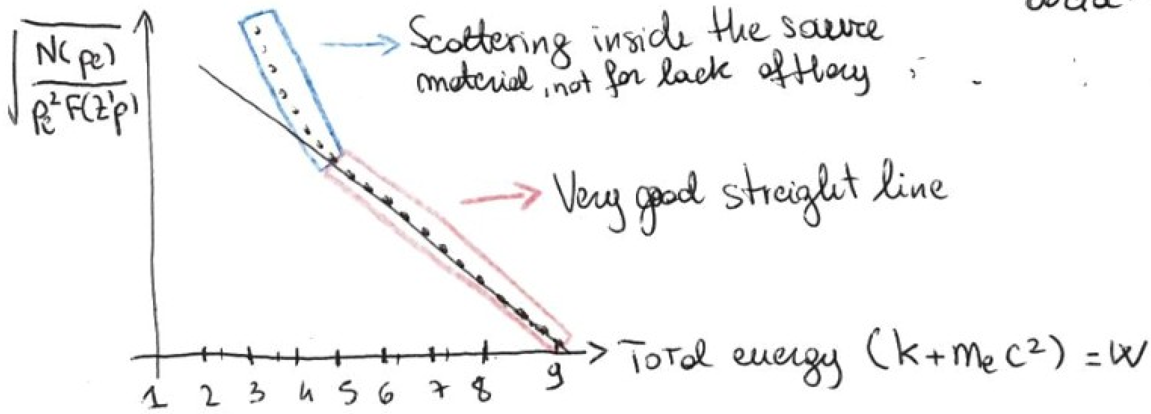
SHAPE OF β SPECTRUM

The equation of the N(p) can be rewritten as (in the allowed approximation)

$$(Q-K) \propto \sqrt{\frac{N(p_e)}{p_e^2 F(Z',p)}}$$

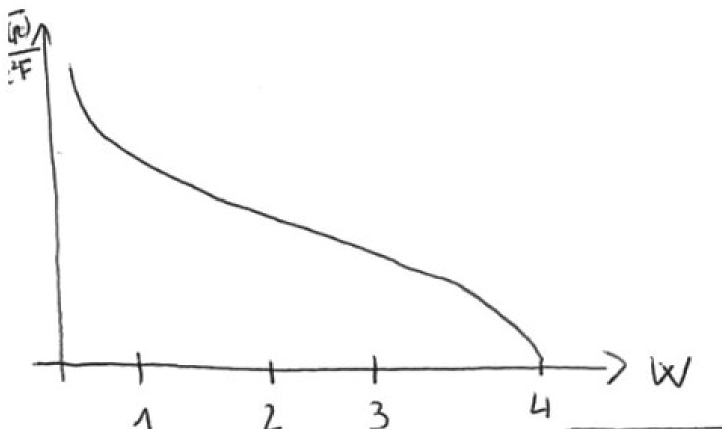
→ plotting $\sqrt{\frac{N(p_e)}{p_e^2 F(Z',p)}}$ vs K should be a straight line, which intercepts the x-axis at the decay energy Q. Such plot is called Kurie plot (or Fermi-Kurie plot or Fermi plot). As an example

$^{66}Ga \rightarrow {}^{66}Zn + e^+ + \nu$

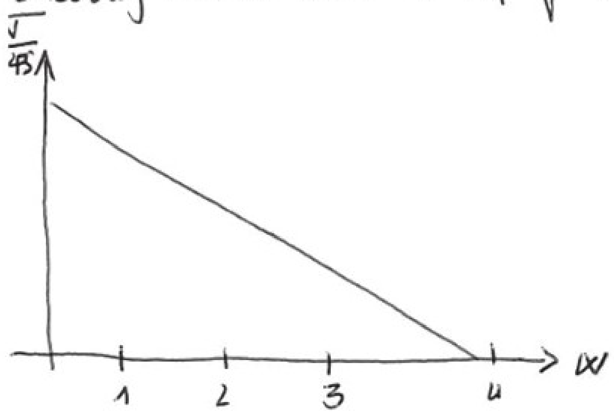


The Fermi-Kurie plot is ok for many β decays.
In case of forbidden decays, the standard Kurie plot does not give a straight line.

$^{91}_{39}Y \rightarrow {}^{91}_{38}Zn + e^+ + \nu$



linearity can be restored if $\sqrt{N(p_e) / p_e^2 F(Z',p) \, S(p_e,p_\nu)}$ is plotted



$S(p_e,p_\nu)$ is called SHAPE FACTOR

TOTAL DECAY RATE

To find total decay rate the $d\lambda$ expression $d\lambda = \frac{2\pi}{\hbar} g^2 |M_{fi}|^2 (4\pi)^2 \frac{p_e^2 dp_e p_\nu^2}{h^6} \frac{dq}{dE_f}$ have to be integrated

$$\lambda = \frac{g^2 |M_{fi}|^2}{2\pi^3 \hbar^7 c^3} \int_0^{p_{MAX}} F(Z', p_e) p_e^2 (Q - T_e)^2 dp_e$$

The integral will depends only on Z' and on E_0 ($c p_{max} = \sqrt{E_0^2 - m_e^2 c^4}$) so

$$f(Z', E_0) = \frac{1}{(m_e c)^3 (m_e c)^2} \int_0^{p_{MAX}} F(Z', p_e) p_e^2 (E_0 - k)^2 dp_e$$

Where all the constants are included to make f without dimensions. $F(Z', E_0)$ is called Fermi integral and is tabulated for values of Z' and E_0. With $\lambda = 0,69/t_{1/2}$ =>

$$f t_{1/2} = 0,69 \frac{2\pi^3 \hbar^7}{g^2 m_e^5 c^4 |M_{fi}|}$$

Comparative half-life or ft value

$\frac{A}{|M_{fi}|}$

=> IT gives a way to compare β decay probabilities in nuclei i.e. in different M_{fi} => In nuclear w.f.

Also in β-decay there is an enormous range of half-lives in β decay:

ft ranges from 10^3 to 10^{20} s. FROM MIN TO GY

The decays with the shortest comparative half lives are know as SUPERALLOWED decays. In case of superallowed decays with ψ_i in 0^+ and ψ_f in 0^+ M_{fi} is easy to be calculated and is $\sqrt{2}$. In case of $0^+ \to 0^+$ decays the ft value should be a "constant" => Within uncertainities that is the case.

In case of $0^+ \to 0^+$ the decay constant g can be evaluated:

$$g = 0,88 \times 10^{-4} \text{ MeV} \cdot \text{fm}^3$$

$J \cdot m^3 = \frac{kg \cdot m^2}{s^2} \cdot m^3$
$\hookrightarrow N \cdot m$

Let's compare it with other variables -> We have to make it dimension less

$$[G] = M L^5 T^{-2}$$

$\hbar = J \cdot s = \frac{kg\, m^2}{s^2} s = M L^2 s^{-1}$ $c = m/s$

And there is no combinations of $\hbar [M L^2 T^{-1}]$ or $c [L T^{-1}]$ which can used to convert g into a dimension less variable.

E.g. $\hbar c^3$ has a dimension $ML^2T^{-1} \cdot L^3T^{-3} = ML^5T^{-4}$ So $\frac{g}{\hbar c^3} = T^2$

We can introduce an arbitrary mass and choose the exponentials i, J, k such that $g/m^i \hbar^j c^k$ is dimensionless.

If $i = -2$, $J = 3$ and $k = -1$ $\Rightarrow G = \frac{g}{m^{-2}\hbar^3 c^{-1}} = g\frac{m^2 c}{\hbar^3}$ ✓

The mass that should be used is not clear. For nucleon-nucleon interaction the nucleon mass should be used. In this way $G = 1{,}0 \cdot 10^{-5}$.

The strong constant for π is $\simeq 1$, so ordering the interactions:

pion - nucleon	1
e.m.	10^{-2}
β-decay (weak)	10^{-5}
gravitational	10^{-39}

Fermi theory is able to reproduce many aspects of the weak interaction, while it fails for others: a theory which describe the weak interaction in terms of exchange ptc (i.e. bosons) is more succesfull in describing such interaction.

THE MASS OF THE NEUTRINO

The Fermi theory is based on the assumption that the rest mass of ν is 0.
This hypotesis can be tested by measuring the energy of β^+ and β^- decays at the end point and see how it behaves...

When we evaluated ~~all~~ the N(K) in Fermi's theory we said that if $m_\nu = 0 \Rightarrow$

$$E_\nu = p_\nu c \Rightarrow \frac{dN}{dE_f} = C\, p_\nu^2 p_e^2\, dp_e \frac{dp_\nu}{dE_f}$$

$$\frac{dp_\nu}{dE_f} = \frac{1}{c}$$ $\Rightarrow$ This won't be valid if $m_\nu \neq 0$. In this case

$$E_\nu = m_\nu c^2 + \frac{p_\nu^2}{2m_\nu}$$

$$E_f = M_e c^2 + m_\nu c^2 + K + \frac{p_\nu^2}{2m_\nu} \qquad dE_f = \frac{p_\nu\, dp_\nu}{m_\nu}$$ (AT A FIXED K)

$$\Rightarrow \frac{dp_\nu}{dE_f} = \frac{m_\nu}{p_\nu} \neq \frac{1}{c}$$ $\Rightarrow$ In this case the shape of the spectrum would change considerably

$$p_\nu = \sqrt{2m_\nu(Q-k)} \qquad \frac{p_\nu^2}{2m_\nu} = Q-k$$

$$\frac{dn}{dE_f} = C\, p_e^2\, dp_e\, \underset{\substack{\uparrow \\ \text{Before it} \\ \text{was } p_\nu^2!}}{p_\nu}$$

$$\Rightarrow N(k) = C_1 \overbrace{\sqrt{k(k+2m_e c^2)}\left(k+m_e c^2\right)}^{A} \cdot \overbrace{p_\nu}^{B}$$

$$p_\nu = \begin{cases} (Q-k)^2 & \text{if } m_\nu = 0 \quad \text{(A)} \\ \sqrt{2m_\nu(Q-k)} & \text{if } m_\nu \neq 0 \quad \text{(B)} \end{cases}$$

The effect of the ν mass will be visible in the tail prt.
If we evaluate $\frac{dN}{dk}$ we would get $N(k)$ vs Q

A) $m_\nu = 0$

$$\frac{dN}{dk} = C_1\left[\sqrt{k(k+2m_eC^2)}(k+2m_eC^2)\cdot 2(Q-k) + (Q-k)^2 \cdot \frac{d}{dk}[A]\right]$$

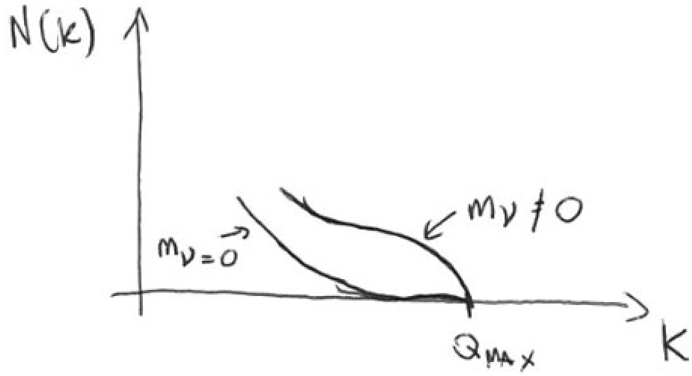
When $Q=k$ both terms are 0 $\Rightarrow$ the $N(k)$ will approach 0 horizontally

B) $m_\nu \neq 0$

$$\frac{dN}{dk} = C_1\left\{\left[A \cdot \underset{\substack{\Uparrow \\ -\frac{1}{2m_\nu\sqrt{Q-k}}}}{\frac{d}{dk}B}\right] + \sqrt{2m_\nu(Q-k)}\;\frac{d}{dk}A\right\}$$

$\Rightarrow$ When $Q=k$ the 1° term goes to ∞
$\Rightarrow$ Drastic change in slope!

Studing the end-point region the expected behaviour is



ANGULAR MOMENTUM AND PARITY SELECTION RULES

So, we have observed that:

$${}^{66}_{31}Ga \rightarrow {}^{66}_{30}Zn + e^+ + \nu$$

OK FERMI/KURIE PLOT

$0^+ \rightarrow 0^+$

$${}^{91}_{39}Y \rightarrow {}^{91}_{38}Ni + e^+ + \nu$$

NOT OK FERMI-KURIE PLOT

$\frac{1}{2}^- \rightarrow \frac{5}{2}^+$

$\Rightarrow$ The essential physics difference is from J^π!

$$I^\pi_p \rightarrow I^\pi_d + \underbrace{J(e+\nu)}_{\text{This makes the difference.}}$$

ALLOWED DECAYS

In the allowed approximation ψ_e and ψ_ν are expanded such that they start from the origin: $\psi_i = \frac{1}{\sqrt{V}}\left[1 + \frac{\vec{p}_i \cdot \vec{r}}{\hbar} + \dots\right]$ $(i = e, \nu)$

In this case e and ν CANNOT carry any orbital momentum, and the only change in the angular momentum of nucleus must result from spins of e^- and ν, each of which has $s = \frac{1}{2}$.

The spins can be parallel $S = 1$ or antiparallel $S = 0$.

If $S=0$ ↑↓ ⇒ FERMI DECAY ⇒ In the allowed approximation $l=0$ $\qquad l=0$

$\Delta I = |I_i - I_f| = 0 \qquad \Rightarrow I_p^\pi = I_d^\pi$

ALLOWED β DECAYS

Selection rules:

If $S=1$ ↑↑ ⇒ GAMOW-TELLER DECAY

TOTAL ANGULAR MOMENTUM

$\Rightarrow I = 1 \qquad (\vec{I} = L + S)$

$\vec{I}_R = \vec{I}_f + \vec{\lambda}$ ⇒ $\vec{I}_d = +1$, $\vec{I}_d = 0$, $\vec{I}_d = -1$

$\Delta I = 0, 1$

$\Delta\pi$ (parity change) = no

Examples of allowed β decay:

$^{14}O \rightarrow {}^{14}N^*$ this is a $0^+ \rightarrow 0^+$ decay to an excited state of ^{14}N ⇒ This is a pure Fermi type allowed decay

AZOTO

$^6He \rightarrow {}^6Li$ this is a $0^+ \rightarrow 1^+$ decay: pure Gamow-Teller allowed decay (Other example: $^{13}B \rightarrow {}^{13}C$ $(\frac{3}{2}^- \rightarrow \frac{1}{2}^-)$ or $^{230}_{89}Pa \rightarrow {}^{230}_{90}Th^*$ $(2^- \rightarrow 3^-)$)

protactinium

$n \rightarrow p$ $\quad \Delta I = 0$ $(\frac{1}{2}^+ \rightarrow \frac{1}{2}^+)$. Both Fermi and Gamov Teller

This is an example of mixed F+GT transitions where the exact proportion of F and GT is determined by the initial and final W.F.

It might be convenient to define the ratio y of amplitudes (⇔ matrix elements)

$$y = \frac{G_F M_F}{G_{GT} M_{GT}}$$ Nuclear matrix elements

If $g_F = g$ (defined for super allowed $0^+ \rightarrow 0^+$ decays) and for $n \rightarrow p$ decay $|M_F| = 1 \Rightarrow Y \propto G_F^2 M_F^2 (1 + y^{-2})$. From neutron decay rate one can evaluate $y = 0{,}467 \pm 0{,}003 \Rightarrow 82\%$ GT; 18% F.

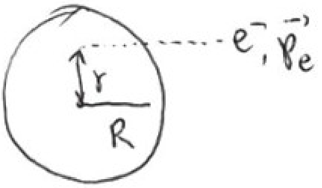
FORBIDDEN DECAYS

These decays are not actually forbidden, but as we saw they are less probable, but allowed in cases where the matrix element vanishes.

The most frequent occurrence of forbidden decays is when the initial and final states have opposite parities ⇒ the selection rules for allowed decay is violated.

To accomplish the change in parity e^- and ν must be emitted with an odd angular momentum relative to the nucleus.

What does it means? $l = 1, 3, 5, \dots$



The angular momentum is defined as $\vec{p}_e \cdot \vec{r}$

The maximum angular momentum is obtained when the e^- is closer to the surface and ⊥ to the direction of $\vec{r}$; in this case $l = p_e \cdot R$ ⇒ MAX l is for max angular momentum

Let's consider a 1 MeV electron ($\equiv k = 1$ MeV)

$$\underbrace{\sqrt{p^2c^2 + m_e^2c^4}}_{\text{TOTAL ENERGY}} = \underbrace{m_e c^2 + k}_{\text{mass + kinetic energy}}$$

$$p^2c^2 + (0{,}5)^2\ \mathrm{MeV}^2 = (0{,}5+1)^2\ \mathrm{MeV}^2$$

$$p^2c^2 = (2{,}25 - 0{,}25)\ \mathrm{MeV}^2 \qquad P_{MAX} \simeq 1{,}4\ \mathrm{MeV/c}$$

$$l_{max} = P_e \cdot R = 1{,}4\ \mathrm{MeV/c} \cdot 5\,\mathrm{fm} \Rightarrow \underbrace{\sqrt{l(l+1)\hbar^2}}_{\sqrt{l_{max}^2}} = 7\ \frac{\mathrm{MeV\ fm}}{c}$$

$$\sqrt{l(l+1)} = \frac{7\,\mathrm{MeV \cdot fm}}{\hbar c} = \frac{7\,\mathrm{MeV \cdot fm}}{200\,\mathrm{MeV \cdot fm}} \simeq \frac{1}{3} \simeq 0{,}3$$

$l(l+1) = 0{,}3^2 \quad l \ll 1 \quad$ → It is unlikely to have $l=1$ w.r.t. $l=0$ but this is more likely to occur that $l = 3, 5, \ldots$

Note that in this case $l = 0$ is ACTUALLY FORBIDDEN!

$l = 1$	First-forbidden	Also in this case decays can be
$l = 2$	Second-forbidden	FERMI / GAMOW-TELLER
$l = 3$	Third-forbidden	$S = 0$ / $S = 1$

For not-allowed β decay the selection rules are

$$l \neq 0 \quad \Rightarrow \Delta I = 0, 1, 2 \quad \Delta\pi = \text{Yes}$$

E.g. $l = 1$ $\quad \Delta\pi = \text{YES}$

$S = 0 \,;\, J = 1 \Rightarrow \Delta I = 0, \pm 1 \quad \equiv 1^{st}$ forbidden Fermi transitions

$l = 1$ $\quad \Delta\pi = \text{YES}$

$S = 1 \,;\, J = 2, 1, 0 \Rightarrow \Delta I = 0, \pm 1, \pm 2 \quad \equiv 1^{st}$ forbidden Gamow-Teller transitions

In cases of not-allowed transitions we already saw that the $\psi_{e,\nu}$ have to be expanded to higher order:

$$\psi_e = \frac{1}{\sqrt{V}}\Big(\underset{l=0}{1} + \underset{l=0,1}{i\frac{\vec{p}_e \cdot \vec{r}}{\hbar}} + \Big(i\frac{\vec{p}_e \cdot \vec{r}}{\hbar}\Big)^2 + \ldots\Big)$$

$\ldots$

The inclusion of higher order l is included in the shape factor of the Fermi-Kurie plot.

Shortly after the publication of the Fermi theory of β decay, Bethe & Peierls pointed out the possibility of inverse β-decay. A nucleons capture a ν or $\bar{\nu}$ and eject e^- or e^+.

$$ {}^A_Z X_N + \nu_e \rightarrow {}^A_{Z+1} Y_{N-1} + e^- $$

$$ {}^A_Z X_N + \bar{\nu}_e \rightarrow {}^A_{Z-1} Y_{N+1} + e^+ $$

The cross-sections of such inverse processes are expected to be extremely small due to the weakness of β decay. Let's consider inverse neutron decay.

$$ \bar{\nu}_e + p \rightarrow n + e^+ $$

The transition probability is given by:

$$ \lambda = \frac{2\pi}{\hbar} |M_{fi}|^2 \frac{dn}{dE_f} $$

And the cross-section σ is defined as transition probability divided by the flux of incoming ν =>

$$ \sigma = \underset{\substack{\uparrow \\ \text{speed} \\ \text{of } \nu}}{\frac{\lambda}{c}} \underset{\substack{\uparrow \\ \text{volume}}}{V} = \frac{2\pi V}{\hbar c} |M_{fi}|^2 \frac{dN}{dE_f} $$

The difference w.r.t. what we have in neutron decay is in $\frac{dN}{dE_f}$ => Different probability for initial and final states.

Neglecting the recoil, but treating e^+ as a relativistic particle we obtain:

$$ \frac{dn_e}{dE_f} = \frac{p_e^2}{2\pi^2\hbar^3} V \frac{dp_e}{dE_p} = \frac{p_e^2}{2\pi^2\hbar^3 c^2} V E_e = \frac{m_0^2 c V}{2\pi^2\hbar^3} \omega \sqrt{\omega^2 - 1} $$

where ω is the reduced energy $\omega = E/m_0c^2$. The M_{fi} correspond to that of n in β decay in which both GT and F ~~cuise~~ contribution are present:

$$|M'_{fi}| = |M'_{fi}(F)|^2 + \frac{g_{GT}^2}{g_F^2}|M'_{fi}(GT)|^2$$

So the cross section is:

$$\sigma_c = \frac{g_F^2 m_0^2}{\pi \hbar^4}\left(|M'_{fi}(F)|^2 + \frac{g_{GT}^2}{g_F^2}|M'_{fi}(GT)|^2\right)\cdot w\sqrt{w^2-1}$$

$$= \left(\frac{\hbar}{m_0 c}\right)^2 G^2 \left\{|M'_{fi}(F)|^2 + \left(\frac{g_{GT}}{g_F}\right)^2 |M'_{fi}(GT)|\right\} w\sqrt{w^2-1}$$

G_F is expressed in terms of G^2. The σ_c is integrated in 4π (both of ν and e^+)

For $|M'_{fi}| \simeq 5$ and the value of G, the $\sigma_c \cong \begin{cases} 8\cdot 10^{-44}\,cm^2 & E_\nu/m_0c^2 = 4,5 \\ 20\cdot 10^{-44}\,cm^2 & = 5,5 \\ 180\cdot 10^{-44}\,cm^2 & = 10,8 \end{cases}$

For $\bar{\nu}_e + p \to n + e^+$ reaction the threshod energy is $E_{\bar{\nu}_e} = 1.8$ MeV.

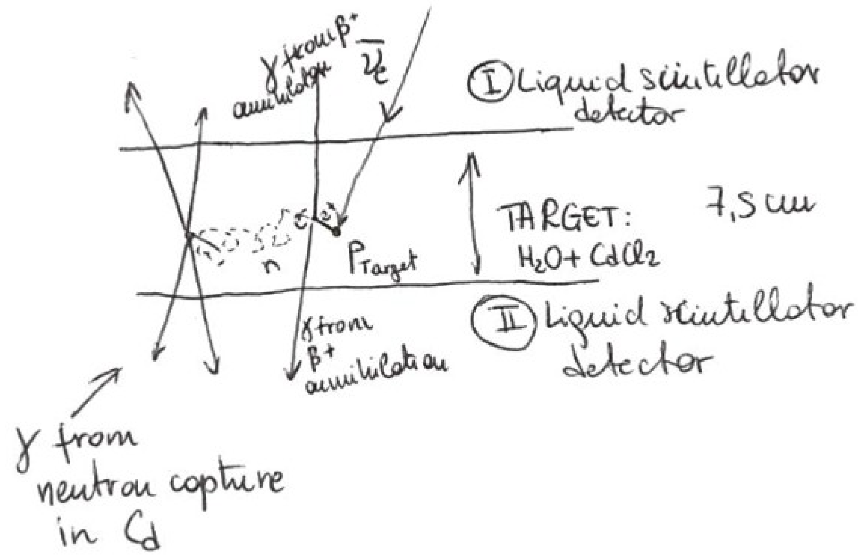
For $E_{\bar{\nu}_e} = 2,8$ MeV the $E_{e^+} = 1$ MeV

The mean free path $l = \frac{1}{n\cdot\sigma_c}$, where n = nuclei $\times\,cm^3$.

For protons in water $n \simeq 3\cdot 10^{22} \Rightarrow l \simeq 3\cdot 10^{20}\,cm \cong 300$ light years.

The reaction was studied by Cowan and Reines in the late 50('58 and '59) using a 1000 MW reactor as source of $\bar{\nu}$. The flux of $\bar{\nu}$ was $\simeq 10^{13}/cm^2 s$. The target consisted on water containg $\simeq 10^{28}$ p in which some $CdCl_2$ was dissolved: some reactions were observed. A positron produced in the capture reaction $\bar{\nu}_e + p \to n + e^+$ quickly annihilates with an electrons within 10^{-9} s producing 2 511 keV γ which travels in opposite directions.

The recoiling neutron slow down ~~scatter~~ throught collisions with protons and is then captured by Cd nuclei by the reaction $Cd(n,\gamma)Cd^*$ producing a γ with total energy = 8 MeV. The neutron capture process takes $\simeq 10^{-5}$ s so a characteristic signature of 2 simultaneous 511 keV γ-ray + a neutron captured few μs later indicates a capture reaction.



The expected rate of events is $F \cdot N \cdot \sigma_c \cdot \varepsilon$ ← Efficiency of detection ($\simeq 3 \cdot 10^{-2}$)

Flux of $\bar{\nu}_e$ — # of p in the target — Capture cross-section

$R \simeq 1$ / hours ($\simeq$ to what was observed).

ARE ν and $\bar{\nu}$ the SAME particle?

The experiment carried by Davis (1955) were based on the observation of inverse reaction of electron capture which for ^{37}Ar

$$^{37}Ar + e^- \longrightarrow {}^{37}Cl + \nu_e$$

$$^{37}Cl + \nu_e \longrightarrow {}^{37}Ar + e^-$$

is

but using $\bar{\nu}_e$. The experiment of Davis did not observed such reaction indicating that ν and $\bar{\nu}$ are not the same ptc.

Even thought $\bar{\nu}$ capture by ^{37}Cl is a forbitten procen, the reaction

$$\nu_e + {}^{37}Cl \rightarrow {}^{37}Ar + e^- \qquad (Q = -0{,}814\ MeV)$$

could be used to detect a ν flux. ^{37}Ar which is formed is unstable and decays back to ^{37}Cl with a $t_{1/2} = 35$ days. The electron capture produces an exited ^{37}Cl with k-shell vacancy $\Rightarrow$ Auger elettron and x-ray emission.

This ν capture reaction was used to detect ν emitted in nuclear, stellar reactions, ... such as:

$$^{7}_{4}Be + p \rightarrow {}^{8}_{5}B + \gamma$$

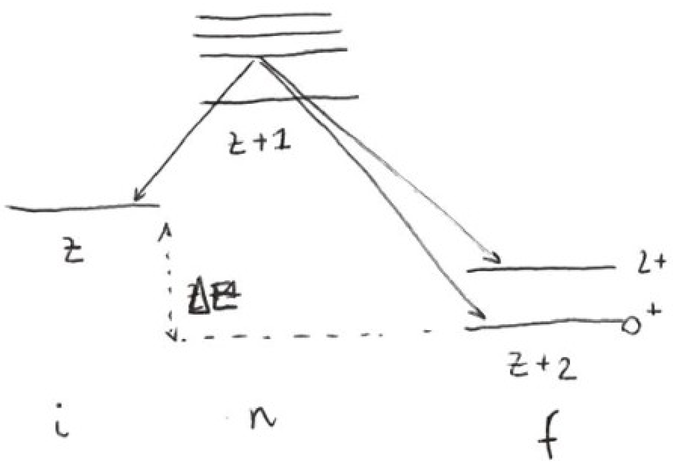
$$^{8}_{5}B \rightarrow {}^{8}_{4}Be^* + e^+ + \nu_e \qquad (E_\nu = 14{,}04\ MeV)$$

Which produce only a small number of ν in sun burning experiment but with enought energy to be initiate the ν capture in ^{37}Cl.

~~Such~~ Experiment ~~performed~~ by Davis led to the surprising observation of the ν nuclear flux to 1/3 of the expected one. Opening the "solar neutrino problem". [Solved by the possibility of ν to oscillate $\Rightarrow$ they MUST have mass]

Double -β decay

Near the bottom part of "mon valley" a double -β decay can occur. It migth happen if: ${}^{A}_{Z}X_N$ has an adjacent nucleus ${}^{A}_{Z+1}Y_{N+1}$ with higher mass while the nucleus ${}^{A}_{Z+2}Y'_{N-2}$ has a lower mass, with a energy difference ΔE



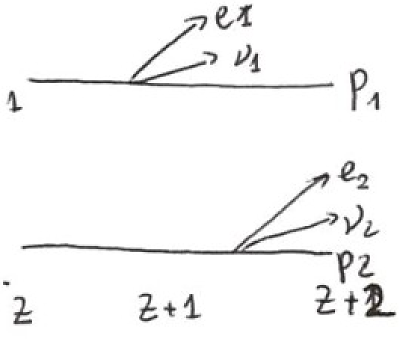
The direct transition from ${}_{Z}X$ to ${}_{Z+2}Y$ is forbidden, since β decay only changes a neutron into a proton.

Decay possibility do exist as second-order decay process, indicating that the intermediate state $|n\rangle$ are virtual states. It is possible to obtain:

$$\langle f|H_{int}|i\rangle = \sum_n \frac{\langle f|H_{int}|n\rangle\langle n|H_{int}|i\rangle}{E_i - E_n}$$

and a simple estimate for double-beta decay process is given by the square of the standard beta decay matrix element. In more complex calculations the individual matrix elements have to be evaluated.

Double-beta decay is a second order process:



$${}^{A}_{Z}X_N \longrightarrow {}^{A}_{Z+2}Y'_{N-2} + e^- + e^- + \bar{\nu}_e + \bar{\nu}_e$$

with the emission of 2 electrons and 2 anti-neutrino.

Nuclei which undergo 2-β decay: $^{48}Ca \rightarrow {}^{48}Ti$ or ^{96}Zr, ^{100}Mo, ^{116}Cd, ^{124}Sn, ^{238}U.

The lifetime estimates are of the order of $T \simeq 10^{20}$ y for a $\Delta E \simeq 5\, m_0 c^2$.

Double-β decays carry a number of very intriguing aspects related to neutrino physics. For example, it was suggested that in Relativistic Quantum mechanics a ν might exists in a way that the charge conjugate state of the original neutrino is identical to (Majorana) or different (Dirac) from the ν itself; i.e:

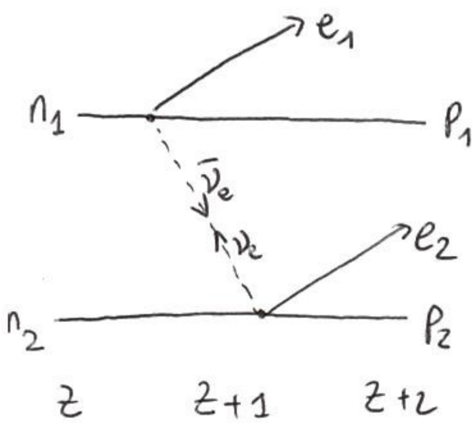
$$C|\nu_e\rangle \equiv |\bar{\nu}_e\rangle \equiv |\nu_e\rangle \quad \text{Majorana}$$

$$C|\nu_e\rangle \equiv |\bar{\nu}_e\rangle \neq |\nu_e\rangle \quad \text{Dirac}$$

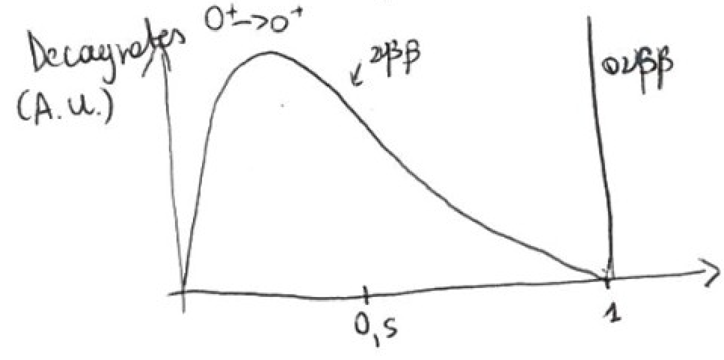
Majorana particles appear in a natural way in GUT theories which unify strong and electro-weak interactions, with the possibility that the lepton number is no longer conserved.

A double-beta decay process can be imaginated in a way where the emitted $\bar{\nu}$ is absorbed as ν giving rise to the process:

$$^{A}_{Z}X_{N} \longrightarrow {}^{A}_{Z+2}Y'_{N-2} + e^- + e^- \longrightarrow \text{Only 2 } e^- \text{ created!}$$



The energy sum of the 2 electrons is constant, in contrast with the usual classic process. The transition probability turns out to be $\simeq 10^5$ shorter than the $(2e^-, 2\bar{\nu})$ process.



The distinction between Majorana and Dirac ptc was tested by Davis experiment. The reaction

$$n \to p + e^- + \bar{\nu}_e \qquad (\bar{\nu}_e \equiv \nu_e) + p \to p + e^-$$

were not observed. So Davis concluded that ν_e was different from $\bar{\nu}_e$.
This discussion had to be changed in the light of Wu experiment, which indicated that the weak interaction violets the parity conservation, implin nat ν has a specific helicity (LEFT-handed for ν and RIGHT-handed for $\bar{\nu}$)
In light of that, Davis experiment and the forbidden character of neutrinoless double beta decay can more easly been explained.
ν and $\bar{\nu}$ never match because of the difference in helicity needed in the nverse reaction:

$$n \to p + e^- + \bar{\nu}\,(R) \quad , \quad \nu(L) + n \to p + e^-$$

ikewise the neutrinoless double beta decay is forbidden even if ν has Majorana character. Note that all these statement are valid only if neutrino is massless, since for massive ptc helicity is a not fixed quantum number.
In fact in 1987 it was presented the first experimental evidence for

neutrino less beta decay:

$$^{82}Se \longrightarrow {}^{82}Kr + e^- + e^-$$

such process has a lifetime $T \cong 1{,}1 \times 10^{20}\ y$