$p \to n$

$-\frac{g_1}{\kappa}\tilde{U}\rho_1\vec{\sigma}\varphi \quad -4\pi g_2 c U^+ \tilde{\psi}\cdot\rho_2\vec{\sigma}\cdot\varphi$

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U-粒子の電子へ轉化する確率

$\sqrt{\frac{4\pi}{\hbar c\kappa}}\cdot\frac{1}{\kappa}$

$$U^- \to e^- + n$$

計算をU粒子靜止系で行ふ

	エネルギー	運動量	
ニウトリノ	$-E$	$-\hbar\vec{K}$	$E = \hbar c K$
電子	E'	$\hbar\vec{K}'$	$E' = \sqrt{\hbar^2c^2K'^2 + \mu^2}$
U粒子	$E_k (= \mu_U)$	$\hbar\vec{k} (= 0)$	

where u, v are the spinor representing the amplitude of the wave function of the initial and final state [illegible]

單位时间の轉移確率

$g_1 \iiint \tilde{\psi}\rho_1(\vec{e}\vec{\sigma})\varphi\, dv$

$$w_0 = \frac{2\pi}{\hbar}\sum_i\sum_f \iint |H^{\vec{K}',-\vec{K}}_{0,1-}|^2 \frac{K'^2V}{(2\pi)^3}\frac{dK'}{d\varepsilon_f}d\Omega$$

$g_1\hbar\sqrt{\frac{2\pi}{m_U c}}$

$$H^{\vec{K}',-\vec{K}}_{N_k=1,N_k'} = i\sqrt{N_k}\; g'\hbar c\sqrt{\frac{2\pi}{E_kV}}(u_1'^+ v) \qquad (\vec{K}'+\vec{K} = \vec{k} = 0)$$

i, 及 f に就ての Σ は 電子及ニウトリノのスピンに関する和.
ε_f は final state の全エネルギーで

$-\frac{\sqrt{4\pi}g'}{\kappa}$

$\kappa c \quad -\frac{\sqrt{\pi}i g'}{\kappa}$

$$\varepsilon_f = E + E' = \hbar cK + \sqrt{\hbar^2c^2K'^2 + \mu^2} = \hbar cK' + \sqrt{\hbar^2c^2K'^2 + \mu^2}$$

$$\frac{d\varepsilon_f}{dK'} = \hbar c + \frac{\hbar^2c^2K'}{\sqrt{\hbar^2c^2K'^2+\mu^2}} = \hbar c\frac{\varepsilon_f}{E'} = \frac{\hbar c\mu_U}{E'} \quad (\text{エネルギー則により } \varepsilon_f = \mu_U)$$

$$N_{jk} = \frac{k_0^2 - k_0^2\delta_{j1}}{\hbar c k_0\kappa^2}\tilde{u}_{jk}u_{jk} \overset{k=0}{=} N_{j0} = \frac{1}{\hbar c\kappa}\tilde{u}_{j0}u_{j0}$$

$$u_{j0} = \sqrt{\frac{1}{\hbar c\kappa}}\cdot\frac{g'}{\kappa}$$

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エネルギー則 $E' + E = \mu_u$

及 Impulssatz $\vec{K}' + \vec{K} = 0$

より

$$K' = K = \frac{\mu_u^2 - \mu^2}{2\hbar c \mu_u}$$

$$E = \frac{\mu_u^2 - \mu^2}{2\mu_u}$$

$$E' = \frac{\mu_u^2 + \mu^2}{2\mu_u}$$

$$w_0 = \frac{1}{4} \frac{g^2}{\hbar^2 c} \frac{(\mu_u^2 - \mu^2)^2 (\mu_u^2 + \mu^2)}{\mu_u^5} \sum_i \sum_f |(u^{*}\beta v)|^2$$

$$\sum_i \sum_f |(u'^{*}\beta v)|^2 = \frac{1}{\cancel{16} EE'}_{4} \, \mathrm{Spur}\,(E + \hbar c \vec{\alpha}\vec{K})\beta(E' + \hbar c \vec{\alpha}\vec{K}' + \beta\mu)\beta$$

$$= \frac{E' - \hbar c K'}{\cancel{4} E'} = 2 \cancel{4} \frac{\mu^2}{\mu_u^2 + \mu^2}$$

従って

$$w_0 = \frac{1}{2\cancel{8}} \frac{g'^2}{\hbar c} \left(\frac{m}{m_u}\right) \frac{mc^2}{\hbar} \frac{(m_u^2 - m^2)^2}{m_u^4}$$

$$\fallingdotseq \frac{1}{2\cancel{8}} \frac{g'^2}{\hbar c} \left(\frac{m}{m_u}\right) \frac{mc^2}{\hbar}$$

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U粒子が速度 βc を有する場合（エネルギー E_k）には轉化確率は

$$w = w_0\sqrt{1-\beta} = \frac{1}{28}\frac{g'^2}{\hbar c}\frac{mc^2}{\hbar}\frac{mc^2}{E_k}$$

mean life τ 及 mean free path L

$$\tau = \frac{1}{w}, \quad L = \beta c \tau$$

数値計算

$$g' = 4\times 10^{-17}, \quad m_U = 100\, m$$

$\underline{m_U c^2}$

$$w = \cancel{0.5}\,2 \times 10^{4}\ \frac{mc^2}{E_k} \quad [\sec^{-1}]$$

$$\tau = 0.5 \times 10^{-4}\ \frac{E_k}{mc^2} \quad [\sec]$$

60)400

$E = 5\times 10^7$

$E_k - \mu_U$	0	10^9 e.v.	10^{10} e.v.	10^{11} e.v.	10^{12} e.v.
τ	$\frac{1}{50}$ 秒	0.4 秒	4 秒	40 秒	~~1分 50秒~~
L	—	1.2×10^5 k.m.	1.2×10^6 k.m.	1.2×10^7 k.m.	1.2×10^8 k.m.

	0.5×10^{-6}	10^{-5}	10^{-4}	10^{-3}	10^{-2}
τ	$\frac{1}{200}$	0.1	1	10	1'40
L	—	3×10^4 km	3×10^5 km	3×10^6 km	3×10^7 km

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中間状態ノ確率

$$\alpha = \frac{|H_{nn'}|^2}{(E_n - E_{n'})^2}$$

$$= 2\pi(g\hbar c)^2 \sum_{k} \frac{1}{E_k} \frac{1}{2}\sum_{q}^{(+)} \sum \frac{(u^*\beta v')(v'^*\beta u)}{(\mu_N - E_k - E')^2}$$

$$\frac{1}{2}\sum^{(+)}\sum \frac{(u^*\beta v')(v'^*\beta u)}{(\mu_N - E_k - E')^2}$$

$$= \frac{1}{4\{(\mu_N - E_k)^2 - E'^2\}^2} \,\mathrm{Spur}\,\beta\{(\mu_N - E_k)^2 + 2(\mu_N - E_k)(\vec{\alpha}\vec{p}' + \beta\mu_p) + (\vec{\alpha}\vec{p}' + \beta\mu_p)(\vec{\alpha}\vec{p}' + \beta\mu_p)\}\times$$

$$\times\beta(1+\beta)$$

$$= \frac{(\mu_N - E_k)^2 + 2(\mu_N - E_k)\mu_P + \mu_P^2 + (\hbar c k)^2}{\{(\mu_N - E_k)^2 - E'^2\}^2}$$

$$= \frac{(\mu_N + \mu_P - E_k)^2 + E_k^2 - \mu_U^2}{\{\mu_N^2 - \mu_P^2 + \mu_U^2 - 2\mu_N E_k\}^2}$$

$$\simeq \frac{(2\mu - E_k)^2 + E_k^2}{4\mu^2 E_k^2}$$

$$\alpha = \frac{g^2}{4\pi\hbar c}\frac{1}{\mu^2}\int \frac{\{(2\mu - E_k)^2 + E_k^2\}}{E_k} dE_k$$

$$= \frac{g^2}{4\pi\hbar c}\frac{1}{\mu^2}\cancel{\int_{\varepsilon_0}\frac{2}{E}} \int \frac{\{(2-\varepsilon)^2 + \varepsilon^2\}}{\varepsilon} d\varepsilon \qquad \mu$$

$$= \frac{g^2}{4\pi\hbar c}\int_{\varepsilon_0}\left(\frac{4}{\varepsilon} - 4 + \varepsilon\right) d\varepsilon = \frac{g^2}{4\pi\hbar c}\cdot\left(4\log\frac{\varepsilon_0}{\varepsilon_0} - 4\varepsilon_0 + \frac{\varepsilon_0^2}{2}\right)$$

中性子 ノ Self-Energy.

$$W = \sum \frac{H_{nn'} H_{n'n}}{E_n - E_{n'}}$$

$$H_{nn'} = i \frac{\sqrt{2\pi}\, g\hbar c}{\sqrt{E_k}} (u^* \beta v')$$

$$H_{n'n} = -i \frac{\sqrt{2\pi}\, g\hbar c}{\sqrt{E_k}} (v'^* \beta u)$$

	始	中間	終
中性子	$E = \mu_N,\ \vec{P} = 0,\ u$	ナシ	$E,\ \vec{P}$
陽子	ナシ	$E',\ \vec{P}',\ v'$	ナシ
U-粒子	ナシ	$E_k,\ \hbar c \vec{k}$	ナシ

$$\begin{cases} E_n = \mu_N \\ E_{n'} = E_k + E' \\ E' = \sqrt{P'^2 + \mu_P^2} \\ \vec{P}' = -\hbar c \vec{k} \end{cases}$$

$$W = 2\pi (g\hbar c)^2 \sum_k \frac{1}{E_k} \frac{1}{2} \sum^{(+)} \sum \frac{(u^* \beta v')(v'^* \beta u)}{\mu_N - E_k - E'}$$

$\frac{1}{2}\sum^{(+)}$: initial state ノ spin ノ平均, $\sum$：中間状態ノ Protonノ状態ニ就テノ 和

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$$\frac{1}{2}\sum^{(+)}\sum \frac{(u^*\beta v')(v'^*\beta u)}{\mu_N - E_k - E'}$$

$$= \frac{1}{4\{(\mu_N - E_k)^2 - E'^2\}} \quad Spur\, \beta(\mu_N - E_k + \vec{\alpha}'\vec{p}' + \beta\mu_P)\beta(1+\beta)$$

$$= \frac{\mu_N - E_k + \mu_P}{\{(\mu_N - E_k)^2 - E'^2\}}$$

$$= \frac{\mu_N + \mu_P - E_k}{\mu_N^2 - \mu_P^2 + \mu_u^2 - 2\mu_N E_k}$$

$$\simeq \frac{2\mu - E_k}{-2\mu E_k} \qquad (\mu \doteq \mu_P \doteq \mu_N)$$

$$W = 2\pi(g\hbar c)^2 \sum_k \frac{1}{E_k^2}\,\frac{E_k - 2\mu}{2\mu}$$

$$= \frac{g^2}{\pi\hbar c}\int \frac{\cancel{E_k} - 2\mu}{2\mu}\, dE_k = -\frac{g^2}{\pi\hbar c}(E_0 - \mu_u)$$

$$\cancel{= \frac{g^2}{\pi\hbar c}\int_{\mu_u}^{E_0} \frac{E_0^2 - \mu_u^2}{4\mu}} \qquad \cong -\mu$$

$$E_0 \cong \left(\frac{\pi\hbar c}{g^2}\right)\mu$$

$$E_0^2 - \mu_u^2 = \cancel{\frac{4\mu^2}{\pi\hbar}}\left(\frac{\pi\hbar c}{g^2}\right)$$

$$E_0^2 = \mu_u^2 + 4\mu^2\left(\frac{\pi\hbar c}{g^2}\right)$$