Vector Meson Theory ニヨル Proton ノ Anomalous Magnetic Moment ノ計算。

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Vector Meson Theory ニヨル Proton ノ Anomalous Magnetic Moment ノ計算。

3次ノ攝動計算ヲ行フト，次ノ三ツノ Process ガ可能デアル。

(1) $P \xrightarrow[NM]{} N + M_k^+ \xrightarrow[NME]{} N + M_k^+ \xrightarrow[NM]{} P$.

(2) $P \xrightarrow[NM]{} N + M_k^+ \xrightarrow[NM]{} P + M_{-k}^- + M_k^+ \xrightarrow[NME]{} P$

(3). $P + (H) \xrightarrow[NME]{} M_k^+ + M_{-k}^- + P \xrightarrow[NM]{} M_k^+ + N \xrightarrow[NM]{} P$

上ノ夫々ニ対シテ trans → trans; trans → long, long → trans; long → long. ナル process ガ考ヘラレル。

I, trans → trans.

Matrix elements: （非相対性論的取扱）。

$$H^{NM,\ trans}_{M_k^+ emission} = \tilde{u}^{(b)} \frac{f}{\varkappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}(\vec{\sigma}, [\vec{j}\times\vec{k}])u^{(a)}$$

$$H^{NM,\ trans}_{M_k^+ absorption} = \tilde{u}^{(a)} \cdot \frac{f}{\varkappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}(\vec{\sigma}, [\vec{j}\times\vec{k}])u^{(b)}$$

$$H^{NM\ trans}_{M_{-k}^- emission} = -\tilde{u}^{(a)} \frac{f}{\varkappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}(\vec{\sigma}, [\vec{j}\times\vec{k}])u^{(b)}$$

$$H^{NM\ trans}_{M_{-k}^- emission} = -\tilde{u}^{(a)} \cdot \frac{f}{\varkappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}(\vec{\sigma}, [\vec{j}\times\vec{k}])u^{(b)}$$

$$H^{ME}_{M_k^+\to M_{k'}^+} = \frac{\hbar ec}{2}\cdot\frac{1}{\sqrt{\varepsilon_k\varepsilon_{k'}}}\int\{([\vec{j}\times\vec{k}],[\vec{A}\times\vec{j}'])+([\vec{j}'\times\vec{k}'],[\vec{A}\times\vec{j}])\}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}$$

$$H^{ME}_{M_k^+, M_{-k'}^-\ creation} = -\frac{\hbar ec}{2}\cdot\frac{1}{\sqrt{\varepsilon_k\varepsilon_{k'}}}\int\{([\vec{j}\times\vec{k}],[\vec{A}\times\vec{j}'])+([\vec{j}'\times\vec{k}'],[\vec{A}\times\vec{j}])\}e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}$$

$$H^{ME}_{M_k^+, M_{-k'}^-\ absorption} = -\frac{\hbar ec}{2}\cdot\frac{1}{\sqrt{\varepsilon_k\varepsilon_{k'}}}\int\{([\vec{j}\times\vec{k}],[\vec{A}\times\vec{j}'])+([\vec{j}'\times\vec{k}'],[\vec{A}\times\vec{j}])\}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}$$

$\vec{j}$: $\vec{k}$ = 垂直ナ単位 vector ; $\varepsilon_k = \hbar c\sqrt{k^2+\varkappa^2}$.

$\vec{\sigma}$: Pauli's spin vector,

u : 重粒子ノ波動函数（二ツノ成分ヲモツ）。

$u^{(a)} = \begin{pmatrix}1\\0\end{pmatrix}$　$\tilde{u}^{(a)} = (1\ 0)$.

(1)

$$W_I^{(1)} = \frac{\pi\hbar^3c^3e\cdot f^2}{\kappa^2}\sum_{k,k'}\sum_{j,j'}\frac{\tilde{u}^{(a)}(\vec{\sigma},[\vec{j}'\times\vec{k}'])(\vec{\sigma},[\vec{j}\times\vec{k}])u^{(a)}}{\varepsilon_k^2\cdot\varepsilon_{k'}^2}$$

$$\cdot\int\{([\vec{j}\times\vec{k}],[\vec{A}\times\vec{j}'])+([\vec{j}'\times\vec{k}'],[\vec{A}\times\vec{j}])\}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}.$$

$\vec{j},\vec{j}'$ ニツイテ $\sum$ ヲ行フト.

$$W_I^{1} = \frac{2\pi f^2 e}{\hbar c\kappa^2}\sum_{k,k'}\int\frac{(\vec{A},\vec{k})\{(\vec{k}\vec{k}')-k'^2\}+(\vec{A}\vec{k}')\{(\vec{k}\vec{k}')-k^2\}}{(k^2+\kappa^2)(k'^2+\kappa^2)}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}$$

$$-i\cdot\frac{2\pi f^2 e}{\hbar c\kappa^2}\sum_{k,k'}\frac{(\vec{A},[\vec{k}\times\vec{k}'])(k_z+k_z')-(\vec{A},\vec{k}+\vec{k}')[\vec{k}\times\vec{k}']_z}{(k^2+\kappa^2)(k'^2+\kappa^2)}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}$$

$\sum_{k,k'}\longrightarrow\frac{1}{(2\pi)^6}\iint d\vec{k}\cdot d\vec{k}'$ ヲ行フト. 1st. term ハ $\vec{k},\vec{k}'$ ノ polar

angles ニツイテノ積分ニヨツテ消失シ, 第二項ヲ積分スルト

$$W_I^{1} = -\frac{2f^2\cdot eH}{3\pi\cdot\hbar c\kappa^2}\int\frac{k^4dk}{(k^2+\kappa^2)^2}.$$

$$W_I^{(2)} = \frac{f^2\pi\hbar^3c^3e}{\kappa^2}\sum_{k,k'}\sum_{j,j'}\frac{\tilde{u}^{(a)}(\vec{\sigma},[\vec{j}'\times\vec{k}'])(\vec{\sigma},[\vec{j}\times\vec{k}])u^{(a)}}{\varepsilon_k^2\varepsilon_{k'}(\varepsilon_k+\varepsilon_{k'})}\int\{([\vec{j}\times\vec{k}],[\vec{A}\times\vec{j}'])$$

$$+([\vec{j}'\times\vec{k}'],[\vec{A}\times\vec{j}])\}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r},$$

$$W_I^{(3)} = \frac{f^2\pi\hbar^3c^3e}{\kappa^2}\sum_{k,k'}\sum_{j,j'}\frac{\tilde{u}^{(a)}(\vec{\sigma},[\vec{j}'\times\vec{k}'])(\vec{\sigma},[\vec{j}\times\vec{k}])u^{(a)}}{\varepsilon_k\varepsilon_{k'}^2(\varepsilon_k+\varepsilon_{k'})}\cdot\int\{([\vec{j}\times\vec{k}],[\vec{A}\times\vec{j}'])$$

$$+([\vec{j}'\times\vec{k}'],[\vec{A}\times\vec{j}])\}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}.$$

$$\frac{1}{\varepsilon_k^2\varepsilon_{k'}(\varepsilon_k+\varepsilon_{k'})}+\frac{1}{\varepsilon_k\varepsilon_{k'}^2(\varepsilon_k+\varepsilon_{k'})}=\frac{1}{\varepsilon_k^2\varepsilon_{k'}^2}$$

デアルカラ $W_I^{(2)}+W_I^{(3)}=W_I^{(1)}.$

$$\therefore\ \underline{\underline{W_I}} = W_I^{(1)}+W_I^{(2)}+W_I^{(3)} = \underline{\underline{-\frac{4f^2eH}{3\pi\cdot\hbar c\kappa^2}\int\frac{k^4dk}{(k^2+\kappa^2)^2}}}.$$

II. trans → long, long → trans.

Matrix elements;

$$
\left\{
\begin{aligned}
H^{NM\ \mathrm{trans}}_{M^+_k\ \mathrm{emission}} &= \tilde{u}^{(b)} \frac{f}{\kappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}(\vec{\sigma},[\vec{j}\times\vec{k}])\,u^{(a)} \\
H^{NM\ \mathrm{long}}_{M^+_k\ \mathrm{emission}} &= -\tilde{u}^{(b)}\cdot \frac{g}{\kappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}\cdot k\, u^{(a)} \\
H^{NM\ \mathrm{trans}}_{M^-_{-k}\ \mathrm{emission}} &= -\tilde{u}^{(a)}\cdot \frac{f}{\kappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}(\vec{\sigma},[\vec{j}\times\vec{k}])\,u^{(b)} \\
H^{NM\ \mathrm{long}}_{M^-_{-k}\ \mathrm{emission}} &= \tilde{u}^{(a)} \frac{g}{\kappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}\cdot k\cdot u^{(b)}
\end{aligned}
\right.
$$

absorption ノ Matrix elements ハ 夫々 上ノ compl. conj.

$$
\left\{
\begin{aligned}
H^{ME}_{M^+_k\mathrm{trans}\to M^+_k\mathrm{long}} &= \frac{ie}{2\kappa}\int\left\{\frac{1}{k'}\sqrt{\frac{\varepsilon_{k'}}{\varepsilon_k}}([\vec{A}\times\vec{k}'],[\vec{j}\times\vec{k}]) - k'\sqrt{\frac{\varepsilon_k}{\varepsilon_{k'}}}(\vec{A},\vec{j})\right\}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r} \\
H^{ME,\ \mathrm{creation}}_{M^+_k\mathrm{trans},\,M^-_{-k}\mathrm{long}} &= \frac{ie}{2\kappa}\int\left\{-\frac{1}{k}\sqrt{\frac{\varepsilon_k}{\varepsilon_{k'}}}([\vec{A}\times\vec{k}],[\vec{j}\times\vec{k}']) - k\sqrt{\frac{\varepsilon_{k'}}{\varepsilon_k}}(\vec{A},\vec{j}')\right\}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r} \\
H^{ME,\ \mathrm{creation}}_{M^+_k\mathrm{long},\,M^-_{-k}\mathrm{trans}} &= \frac{ie}{2\kappa}\int\left\{-\frac{1}{k'}\sqrt{\frac{\varepsilon_{k'}}{\varepsilon_k}}([\vec{A}\times\vec{k}'],[\vec{j}\times\vec{k}]) - k'\sqrt{\frac{\varepsilon_k}{\varepsilon_{k'}}}(\vec{A},\vec{j})\right\} e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}
\end{aligned}
\right.
$$

上ノ各ノ process ノ Matrix element ハ 夫々 上ノ compl. conj.

(1) $\to +\mathrm{trans} \to +\mathrm{long} \to$; (2) $\to +\mathrm{trans} \to \begin{smallmatrix}+\mathrm{trans}\\-\mathrm{long}\end{smallmatrix} \to$,

(3) $\to \begin{smallmatrix}+\mathrm{trans}\\-\mathrm{long}\end{smallmatrix} \to +\mathrm{trans} \to$, (4) $\to +\mathrm{long} \to +\mathrm{trans} \to$

(5) $\to +\mathrm{long} \to \begin{smallmatrix}+\mathrm{long}\\-\mathrm{trans}\end{smallmatrix} \to$, (6) $\to \begin{smallmatrix}+\mathrm{long}\\-\mathrm{trans}\end{smallmatrix} \to +\mathrm{long} \to$.

$$
W^{(1)}_{\mathrm{II}} = -\frac{i\pi\hbar^2c^2e\cdot fg}{\kappa^3}\sum_{\substack{k,k'\\ j,j'}}\frac{\tilde{u}^{(a)}\cdot k'(\vec{\sigma},[\vec{j}\times\vec{k}])\,u^{(a)}}{\varepsilon_k\varepsilon_{k'}\sqrt{\varepsilon_k\varepsilon_{k'}}}\int\left\{\frac{1}{k'}\sqrt{\frac{\varepsilon_{k'}}{\varepsilon_k}}([\vec{A}\times\vec{k}'],[\vec{j}\times\vec{k}]) - k'\sqrt{\frac{\varepsilon_k}{\varepsilon_{k'}}}(\vec{A},\vec{j})\right\}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}
$$

$$
= -\frac{i\pi\hbar^2c^2e\cdot fg}{\kappa^3}\sum_{k,k'}\frac{1}{\varepsilon_k\varepsilon_{k'}\sqrt{\varepsilon_k\varepsilon_{k'}}}\int\left[\sqrt{\frac{\varepsilon_{k'}}{\varepsilon_k}}\left\{(\vec{k}\vec{k}')[\vec{A}\times\vec{k}]_z + (\vec{A},\vec{k})[\vec{k}\times\vec{k}']_z\right\} - k'^2\cdot\sqrt{\frac{\varepsilon_k}{\varepsilon_{k'}}}[\vec{A}\times\vec{k}]_z\right\}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}d\vec{r}
$$

i.e.

$$W_{\mathrm{II}}^{(1)} = -\frac{i\pi e\cdot fg}{\hbar c\kappa^3}\sum_{k,k'}\int \frac{(\vec{k}\vec{k}')[\vec{A}\times\vec{k}]_z + (\vec{A},\vec{k})[\vec{k}\times\vec{k}']_z}{(k^2+\kappa^2)\sqrt{k'^2+\kappa^2}}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}\,d\vec{r}$$

$$+\frac{i\pi e\cdot fg}{\hbar c\kappa^3}\sum_{k,k'}\int \frac{k^2\cdot[\vec{A}\times\vec{k}]_z}{(k^2+\kappa^2)\sqrt{k'^2+\kappa^2}}\, e^{i(\vec{k}-\vec{k}',\vec{r})}\,d\vec{r}$$

同様にして

$$W_{\mathrm{II}}^{(2)} = \frac{i\pi e fg}{\hbar c\kappa^3}\sum_{k,k'}\int \frac{(\vec{k}\vec{k}')[\vec{A}\times\vec{k}]_z + (\vec{A},\vec{k})[\vec{k}\times\vec{k}']_z}{(k^2+\kappa^2)(\sqrt{k^2+\kappa^2}+\sqrt{k'^2+\kappa^2})}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}\,d\vec{r}$$

$$+\frac{i\pi e fg}{\hbar c\kappa^3}\sum_{k,k'}\int \frac{k^2[\vec{A}\times\vec{k}]_z\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}}{\sqrt{k^2+\kappa^2}\sqrt{k'^2+\kappa^2}(\sqrt{k^2+\kappa^2}+\sqrt{k'^2+\kappa^2})}\,d\vec{r}.$$

$$W_{\mathrm{II}}^{(3)} = -\frac{i\pi e\cdot fg}{\hbar c\kappa^3}\sum_{k,k'}\frac{(\vec{k}\vec{k}')[\vec{A}\times\vec{k}]_z + (\vec{A},\vec{k})[\vec{k}\times\vec{k}']_z}{(k^2+\kappa^2)(\sqrt{k^2+\kappa^2}+\sqrt{k'^2+\kappa^2})}\cdot e^{-i(\vec{k}-\vec{k}',\vec{r})}\,d\vec{r}$$

$$-\frac{i\pi e fg}{\hbar c\kappa^3}\sum_{k,k'}\frac{k^2[\vec{A}\times\vec{k}]_z\cdot e^{-i(\vec{k}-\vec{k}',\vec{r})}}{\sqrt{k^2+\kappa^2}\sqrt{k'^2+\kappa^2}(\sqrt{k^2+\kappa^2}+\sqrt{k'^2+\kappa^2})}\,d\vec{r}$$

$$W_{\mathrm{II}}^{(4)} = \frac{i\pi e fg}{\hbar c\kappa^3}\sum_{k,k'}\frac{(\vec{k}\vec{k}')[\vec{A}\times\vec{k}]_z + (\vec{A},\vec{k})[\vec{k}\times\vec{k}']_z}{(k^2+\kappa^2)\sqrt{k'^2+\kappa^2}}\cdot e^{-i(\vec{k}-\vec{k}',\vec{r})}\,d\vec{r}$$

$$-\frac{i\pi e fg}{\hbar c\kappa^3}\sum_{k,k'}\frac{k^2\cdot[\vec{A}\times\vec{k}]_z}{(k^2+\kappa^2)\sqrt{k'^2+\kappa^2}}\cdot e^{-i(\vec{k}-\vec{k}',\vec{r})}\,d\vec{r}$$

$$W_{\mathrm{II}}^{(5)} = \frac{i\pi e fg}{\hbar c\kappa^3}\sum_{k,k'}\frac{(\vec{k}\vec{k}')[\vec{A}\times\vec{k}]_z + (\vec{A},\vec{k})[\vec{k}\times\vec{k}']_z}{\sqrt{k^2+\kappa^2}\cdot\sqrt{k'^2+\kappa^2}(\sqrt{k^2+\kappa^2}+\sqrt{k'^2+\kappa^2})}\, e^{-i(\vec{k}-\vec{k}',\vec{r})}\,d\vec{r}$$

$$+\frac{i\pi e fg}{\hbar c\kappa^3}\sum_{k,k'}\frac{k^2[\vec{A}\times\vec{k}]_z\cdot e^{-i(\vec{k}-\vec{k}',\vec{r})}}{(k^2+\kappa^2)(\sqrt{k^2+\kappa^2}+\sqrt{k'^2+\kappa^2})}\,d\vec{r}$$

$$W_{\mathrm{II}}^{(6)} = -\frac{i\pi e fg}{\hbar c\kappa^3}\sum_{k,k'}\frac{(\vec{k}\vec{k}')[\vec{A}\times\vec{k}]_z + (\vec{A},\vec{k})[\vec{k}\times\vec{k}']_z}{\sqrt{k^2+\kappa^2}\sqrt{k'^2+\kappa^2}(\sqrt{k^2+\kappa^2}+\sqrt{k'^2+\kappa^2})}\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}\,d\vec{r}$$

$$-\frac{i\pi e fg}{\hbar c\kappa^3}\sum_{k,k'}\frac{k^2[\vec{A}\times\vec{k}]_z\cdot e^{i(\vec{k}-\vec{k}',\vec{r})}}{(k^2+\kappa^2)(\sqrt{k^2+\kappa^2}+\sqrt{k'^2+\kappa^2})}\,d\vec{r}.$$

上ニ示テ $W_{II}^{(1)}$ ト $W_{II}^{(4)}$, $W_{II}^{(2)}$ ト $W_{II}^{(3)}$, $W_{II}^{(5)}$ ト $W_{II}^{(6)}$ ハ 夫々 互ニ compl. conj. ニナッテ オル。

$$W_{II}^{(1)} + W_{II}^{(2)} + W_{II}^{(6)}$$

$$= -\frac{2i\pi e f g}{\hbar c \varkappa^3} \sum_{k,k'} \int \frac{\{(\vec{k}\vec{k}') - k^2\}[\vec{A}\times\vec{k}]_z + (\vec{A},\vec{k})[\vec{k}\times\vec{k}']_z}{\sqrt{k^2+\varkappa^2}\sqrt{k'^2+\varkappa^2}\,(\sqrt{k^2+\varkappa^2}+\sqrt{k'^2+\varkappa^2})} \cdot e^{i(\vec{k}-\vec{k}',\vec{r})} d\vec{r}$$

$$\sum_{k,k'} \to \frac{1}{(2\pi)^6} \iint d\vec{k}\, d\vec{k}'$$ ヲ行フト、

$$\iiint \frac{\{(\vec{k}\vec{k}') - k^2\}[\vec{A}\times\vec{k}]_z \cdot e^{i(\vec{k}-\vec{k}',\vec{r})}}{\sqrt{k^2+\varkappa^2}\sqrt{k'^2+\varkappa^2}\,(\sqrt{k^2+\varkappa^2}+\sqrt{k'^2+\varkappa^2})} \cdot d\vec{r}\, d\vec{k}\, d\vec{k}' = -\frac{16\pi^4 i H}{3} \int \frac{k^4\, dk}{\sqrt{k^2+\varkappa^2}^{\,3}}.$$

$$\iiint \frac{(\vec{A}\vec{k})[\vec{k}\times\vec{k}']_z \cdot e^{i(\vec{k}-\vec{k}',\vec{r})}}{\sqrt{k^2+\varkappa^2}\sqrt{k'^2+\varkappa^2}\,(\sqrt{k^2+\varkappa^2}+\sqrt{k'^2+\varkappa^2})} d\vec{r}\, d\vec{k}\, d\vec{k}' = \frac{16\pi^4 i H}{3} \int \frac{k^4\, dk}{\sqrt{k^2+\varkappa^2}^{\,3}}.$$

$$\therefore\quad W_{II}^{(1)} + W_{II}^{(2)} + W_{II}^{(6)} = 0.$$

$$\therefore\quad \underline{\underline{W_{II}}} = \sum_{\nu=1}^{6} W_{II}^{(\nu)} = 2\,R_e\left(W_{II}^{(1)} + W_{II}^{(2)} + W_{II}^{(6)}\right) = \underline{\underline{0}}.$$

III. long. → long.

Matrix elements:

$$\begin{cases} H^{NM\ long}_{M_k^+\ emission} = -\tilde{u}^{(a)} \cdot \dfrac{g}{\varkappa} \sqrt{\dfrac{2\pi\hbar^2 c^2}{\varepsilon_k}} \cdot k\, u^{(a)}. \\ H^{NM\ long}_{M_{-k}^-\ emission} = \tilde{u}^{(a)} \dfrac{g}{\varkappa} \sqrt{\dfrac{2\pi\hbar^2 c^2}{\varepsilon_k}}\, k \cdot u^{(a)}. \end{cases}$$

absorption ニ対シテハ compl. conj.

$$\begin{cases} H^{ME}_{M_k^+ long \to M_{k'}^+ long} = -\dfrac{\hbar e c}{2} \cdot \dfrac{1}{\sqrt{\varepsilon_k \varepsilon_{k'}}} \int \left\{ \dfrac{k}{k'}(\vec{A},\vec{k}') + \dfrac{k'}{k}(\vec{A},\vec{k}) \right\} \cdot e^{i(\vec{k}-\vec{k}',\vec{r})} d\vec{r} \\ H^{ME,\ creation}_{M_k^+ long,\ M_{-k'}^- long} = \dfrac{\hbar e c}{2} \cdot \dfrac{1}{\sqrt{\varepsilon_k \varepsilon_{k'}}} \int \left\{ \dfrac{k}{k'}(\vec{A}\vec{k}') + \dfrac{k'}{k}(\vec{A}\vec{k}) \right\} e^{i(\vec{k}-\vec{k}',\vec{r})} d\vec{r}. \end{cases}$$

逆 process ニ対シテハ compl. conj.

$$W_{III}^{(1)} = -\frac{\pi e g^2}{\hbar c \kappa^2} \sum_{k,k'} \frac{k^2(\vec{A}\vec{k}') + k'^2(\vec{A}\vec{k})}{(k^2+\kappa^2)(k'^2+\kappa^2)} \cdot e^{i(\vec{k}-\vec{k}', \vec{r})} d\vec{r}$$

$\sum_{k,k'} \longrightarrow \frac{1}{(2\pi)^6} \iint d\vec{k}\, d\vec{k}'$ ヲ行フト. $\vec{k}, \vec{k}'$ ノ polar angle ノ積分ニヨッテ $W_{III}^{(1)}$ ハ消失スル。即チ

$$W_{III}^{(1)} = 0.$$

$W_{III}^{(2)}$, $W_{III}^{(3)}$ ニツイテモ同様デアル。故ニ

$$\underline{W_{III} = 0.}$$

従ッテ3次ノ攝動計算カラ得ラレル攝動エネルギーハ

$$W = -\frac{4f^2 eH}{3\pi \cdot \hbar c \kappa^2} \int \frac{k^4\, dk}{(k^2+\kappa^2)^2}.$$

IV. 重粒子, 中間子, 光子ノ direct interaction ガ働イテクル process ヲ考ヘル。ココニハ次ノ4ツガ考ヘラレル。

$$\begin{cases}
(1)\quad P \xrightarrow[NM]{} N + M_k^{+,\,\mathrm{trans}} \xrightarrow[NME]{} P, \\
(2)\quad P \xrightarrow[NME]{} N + M_k^{+\,\mathrm{trans}} \xrightarrow[NM]{} P. \\
(3)\quad P \xrightarrow[NM]{} N + M_k^{+\,\mathrm{long}} \xrightarrow[NME]{} P. \\
(4)\quad P \xrightarrow[NME]{} N + M_k^{+\,\mathrm{long}} \xrightarrow[NM]{} P.
\end{cases}$$

Meson ノ場ヲ U, $U^\dagger$ トシテ

$$\begin{cases}
U = \sum_{k,j} \left\{ i\sqrt{\frac{2\pi\hbar^2 c^2 \kappa^2}{\varepsilon_k}} (a_k - b_k^*) \cdot \vec{j} + \sqrt{2\pi\varepsilon_k} (A_k^* + B_k^*) \cdot \frac{\vec{k}}{k} \right\} e^{i(\vec{k}\vec{r})} \\
U^\dagger = \sum_{k,j} \left\{ \sqrt{\frac{\varepsilon_k}{8\pi c^2 \kappa^2}} (a_k^* + b_k) \cdot \vec{j} + i\sqrt{\frac{\hbar^2}{8\pi\varepsilon_k}} (A_k^* - B_k) \cdot \frac{\vec{k}}{k} \right\} e^{-i(\vec{k}\vec{r})}
\end{cases}$$

ナル展開ヲ用ヒ, 重粒子トMeson トノ interaction, 重粒子ト電磁場ト Meson トノ direct interaction ヲ夫々

$$H^{NM} = \frac{4\pi g_1 c}{\kappa}\left(\mathrm{div}\, U^{\dagger}\cdot M_0 + \mathrm{div}\, \tilde{U}^{\dagger}\cdot \tilde{M}_0\right) - \frac{g_1}{\kappa}\left(\tilde{U}M + U\tilde{M}\right)$$

$$+ 4\pi g_2 c\left(U^{\dagger}T + \tilde{U}^{\dagger}\tilde{T}\right) + \frac{g_2}{\kappa^2}\left(\mathrm{curl}\, U\cdot\tilde{S} + \mathrm{curl}\, \tilde{U}\cdot S\right)$$

$$+ \frac{4\pi}{\kappa^2}\left(g_1^2 \tilde{M}_0 M_0 + g_2^2 \tilde{S}S\right)$$

$$H^{NME} = \frac{4\pi i g_1 e}{\hbar\kappa}\left(AU^{\dagger}M_0 - A\tilde{U}^{\dagger}\tilde{M}_0\right) + \frac{i g_2 e}{\hbar c\kappa^2}\left([A\tilde{U}]S - [AU]\tilde{S}\right),$$

$$\left(\begin{array}{l} \vec{M} = \tilde{\Psi}(\vec{\alpha}\Pi^*)\Psi, \quad M_0 = \tilde{\Psi}\Pi^*\Psi, \\ \vec{T} = -\tilde{\Psi}\rho_2\vec{\sigma}\Pi^*\Psi, \quad \vec{S} = \tilde{\Psi}\rho_3\vec{\sigma}\Pi^*\Psi. \\ \tilde{\Psi}, \Psi;\ \text{重粒子ノ波動函数.} \\ \Pi^*:\ \text{proton ヲ neutron ニ変ヘル operator} \end{array}\right)$$

トスルト. Matrix elements ハ次ノ如クナル.

$$H^{NM,\,trans}_{M_k^+\,emission} = \tilde{u}^{(k)}\left[i g_1\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}(\vec{\alpha},\vec{j}) - \frac{g_2}{\kappa}\sqrt{2\pi\varepsilon_k}\,\rho_2(\vec{\sigma}\vec{j}) + \frac{g_2}{\kappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}\,\rho_3(\vec{\sigma},[\vec{j}\times\vec{k}])\right] \cdot u^{(a)}\,\Pi^*$$

$$H^{NM\,long}_{M_k^+\,emission} = \tilde{u}^{(k)}\cdot\left[\frac{g_1}{\kappa}\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}\cdot k - \frac{g_1}{\kappa}\sqrt{2\pi\varepsilon_k}\cdot\frac{1}{k}(\vec{\alpha}\vec{k}) - i g_2\sqrt{\frac{2\pi\hbar^2c^2}{\varepsilon_k}}\cdot\frac{1}{k}\,\rho_2(\vec{\sigma}\vec{k})\right] \cdot u^{(a)}\,\Pi^*$$

absorption ノ Matrix elements ハ 上ノ compl. conj.

$$H^{NME,\,trans}_{M_k^+\,\cancel{emission}\ absorption} = \int \tilde{u}^{(a)}\left[-i\frac{g_1 e}{\hbar c\kappa^2}\sqrt{2\pi\varepsilon_k}\,(\vec{A}\vec{j}) + \frac{g_2 e}{\kappa}\sqrt{\frac{2\pi}{\varepsilon_k}}\,\rho_3(\vec{\sigma},[\vec{A}\times\vec{j}])\right] u^{(k)}\, d\vec{r}\cdot\Pi$$

$$H^{NME.\,long}_{M_k^+\,absorption} = \int \tilde{u}^{(a)}\cdot\left[-\frac{g_1 e}{\kappa}\sqrt{\frac{2\pi}{\varepsilon_k}}\cdot\frac{1}{k}(\vec{A}\vec{k}) - i\frac{g_2 e}{\hbar c\kappa^2}\sqrt{2\pi\varepsilon_k}\cdot\frac{1}{k}\,\rho_3(\vec{\sigma},[\vec{A}\times\vec{k}])\right] \cdot u^{(k)}\, d\vec{r}\cdot\Pi.$$

emission ノ matrix elements ハ 上ノ compl. conj.

u ハ Dirac ノ spinor,

$$u^{(a)} = \begin{pmatrix}1\\0\\0\\0\end{pmatrix}, \qquad \tilde{u}^{(a)} = (1\ 0\ 0\ 0).$$

$$W_{IV}^{(1)} = -\sum_{k,j}\sum \int \tilde{u}^{(a)}\left\{ a_1(k)(\vec{A},\vec{j}) + b_2(k)\rho_3(\vec{\sigma},[\vec{A}\times\vec{j}\,])\right\}\cdot u^{(b)}\cdot \tilde{u}^{(b)}\left\{ c_1(k)(\vec{\alpha}\vec{j})\right.$$

$$\left. + d_2(k)\,\rho_2(\vec{\sigma}\vec{j}) + e_2(k)\rho_3(\vec{\sigma},[\vec{j}\times\vec{k}\,])\right\}\cdot u^{(a)}\cdot d\vec{r}\cdot \Big/ E_k + \varepsilon_k - Mc^2.$$

$$\begin{cases} a_\nu(k) \equiv -i\cdot\dfrac{g_\nu e}{\hbar c\varkappa^2}\sqrt{2\pi\varepsilon_k}, \quad b_\nu(k) \equiv \dfrac{g_\nu e}{\varkappa}\sqrt{\dfrac{2\pi}{\varepsilon_k}}, \quad c_\nu(k) \equiv i\hbar c g_\nu\sqrt{\dfrac{2\pi}{\varepsilon_k}}, \\ d_\nu(k) \equiv -\dfrac{g_\nu}{\varkappa}\sqrt{2\pi\varepsilon_k}, \quad e_\nu(k) \equiv \dfrac{\hbar c g_\nu}{\varkappa}\sqrt{\dfrac{2\pi}{\varepsilon_k}}, \qquad (\nu = 1, 2) \\ E_k = \sqrt{\hbar^2c^2k^2 + M^2c^4}, \qquad M : \text{重粒子, Mass.} \end{cases}$$

$$E_k u^{(b)} = H(k)\,u^{(b)}, \qquad H(k) = \hbar c\rho_1(\vec{\sigma}\vec{k}) + \rho_3 Mc^2$$

ヲ用ヒ, 且

$$Mc^2 \gg \hbar c k, \quad \hbar c\varkappa (= \mu c^2) \quad (\mu : \text{Meson, Mass})$$

ナル近似ヲ行フト

$$W_{IV}^{(1)} = -\frac{1}{2}\sum_{k,j}\frac{1}{\varepsilon_k}\int \tilde{u}^{(a)}\cdot\left\{ a_1(k)(\vec{A}\vec{j}) + b_2(k)\rho_3(\vec{\sigma},[\vec{A}\times\vec{j}\,])\right\}\cdot(1+\rho_3)$$

$$\cdot\left\{ c_1(k)(\vec{\alpha}\vec{j}) + d_2(k)\cdot\rho_2(\vec{\sigma}\vec{j}) + e_2(k)\rho_3(\vec{\sigma},[\vec{j}\times\vec{k}\,])\right\}\cdot u^{(a)}\cdot d\vec{r}$$

$$= -\frac{1}{2}\sum_{k,j}\int\frac{1}{\varepsilon_k}\tilde{u}^{(a)}\left[a_1(k)e_2(k)(\vec{\sigma},[\vec{j}\times\vec{k}\,])(\vec{A},\vec{j}) + b_2(k)e_2(k)(\vec{\sigma},[\vec{A}\times\vec{j}\,])(\vec{\sigma},[\vec{j}\times\vec{k}\,])\right]$$

$$\cdot(1+\rho_3)\,u^{(a)}\cdot d\vec{r}$$

$\sum_j$ ヲ行フト

$$W_{IV}^{(1)} = -\frac{1}{2}\sum_k\int\frac{1}{\varepsilon_k}\cdot\tilde{u}^{(a)}\left[e_2(k)\{a_1(k) - i b_1(k)\}(\vec{\sigma},[\vec{A}\times\vec{k}\,]) - 2b_2(k)e_2(k)(\vec{A}\vec{k})\right]$$

$$\cdot(1+\rho_3)\,u^{(a)}\cdot d\vec{r}$$

$$= -\sum_k\int\frac{1}{\varepsilon_k}\left[e_2(k)\{a_1(k) - i b_1(k)\}[\vec{A}\times\vec{k}\,]_z - 2b_2(k)e_2(k)(\vec{A}\vec{k})\right]\cdot d\vec{r}$$

i.e.

$$W_{IV}^{(1)} - i\frac{2\pi e\, g_1 g_2}{\hbar c \varkappa^3 \cdot (2\pi)^3}\iint \frac{[\vec{A}\times\vec{k}]_z}{\sqrt{k^2+\varkappa^2}}\, d\vec{k}\, d\vec{r}$$

$$+\, i\frac{2\pi e \cdot g_2^2}{\hbar c \varkappa^2 \cdot (2\pi)^3}\iint \frac{[\vec{A}\times\vec{k}]_z}{(k^2+\varkappa^2)}\, d\vec{k}\, d\vec{r} + \frac{4\pi e \cdot g_2^2}{\hbar c \varkappa^2 \cdot (2\pi)^3}\iint \frac{(\vec{A}\vec{k})}{k^2+\varkappa^2}\, d\vec{k}\, d\vec{r}.$$

各積分ハ イヅレモ $\vec{k}$ ノ polar angle ノ積分デ消失スルカラ

$$W_{IV}^{(1)} = 0.$$

同様ニシテ

$$W_{IV}^{(2)} = 0.$$

$$W_{IV}^{(3)} = -\sum_k \sum \int \tilde{u}^{(a)}\left[-b_1(k)\frac{1}{k}(\vec{A}\vec{k}) + a_2(k)\cdot\frac{1}{k}\rho_3(\vec{\sigma}, [\vec{A}\times\vec{k}])\right]\cdot u^{(k)} \cdot \tilde{u}^{(k)}$$

$$\cdot\left[e_1(k)\cdot k + d_1(k)\frac{1}{k}(\vec{\alpha}\vec{k}) - c_2(k)\frac{1}{k}\rho_2(\vec{\sigma}\vec{k})\right] u^{(a)} d\vec{r} \Big/ E_k + \varepsilon_k - Mc^2$$

$W_{IV}^{(1)}$ ト同様ニ計算スルト

$$W_{IV}^{(3)} = -\sum_k \int \frac{1}{\varepsilon_k}\left\{-b_1(k)\cdot e_1(k)(\vec{A}\vec{k}) + a_2(k)\, e_1(k)\, [\vec{A}\times\vec{k}]_z\right\} d\vec{r}$$

$\sum_k \longrightarrow \frac{1}{(2\pi)^3}\int d\vec{k}$ ヲ行フト. $\vec{k}$ ノ polar angle ノ積分ニヨッテ

消失スル。 即チ

$$W_{IV}^{(3)} = 0.$$

同様ニシテ

$$W_{IV}^{(4)} = 0.$$

従ッテ

$$\underline{\underline{W_{IV} = \sum_{\nu=1}^{4} W_{IV}^{(\nu)} = 0.}}$$

即チ direct interaction ノ影響ハアラハレテ来ナイ。従ッテ結局 Z-方向ノ一様ナ磁場内ニ Z-方向ノ spin ヲモッタ proton ガ存在スルトキノ, proton ノ anomalous moment ニヨッテ生ズル extra energy ハ

$$W(H) = -\frac{4f^2 eH}{3\pi\cdot\hbar c\kappa^2}\cdot\int\frac{k^4 dk}{(k^2+\kappa^2)^2}$$

デ与ヘラレルコトニナル。従ッテ proton ノ anomalous magnetic moment ハ

[illegible]

~~デ与ヘラレルコトニナル。~~

$$\frac{4f^2}{3\pi\hbar c}\cdot\frac{1}{\kappa}\int\frac{k^4 dk}{(k^2+\kappa^2)^2}\cdot\frac{e\hbar}{Mc}$$

デ与ヘラレルコトニナル。