

ESTRUCTURA DE LA MATERIA 4

2DO CUATRIMESTRE 2025

CLASE 15

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CLASE 15: Interacciones débiles

Temas: fenomenología, teoría efectiva de Fermi, violación de paridad, mixing, SU(2)

fenomenología: si hay neutrinos, es débil...

decaimientos de piones cargados

$$\begin{array}{llll} \pi^+ (u\bar{d}) \longrightarrow \mu^+ \nu_\mu & (99.98\%) & 2.6 \cdot 10^{-8} s & \\ \pi^- (d\bar{u}) \longrightarrow \mu^- \bar{\nu}_\mu & & & \text{e.m.} \sim 10^{-16} s \\ & & & \text{fuertes.} \sim 10^{-23} s \end{array}$$

ejemplo e.m. $\pi^0 (u\bar{u} - d\bar{d}) \longrightarrow \gamma\gamma \quad (99.79\%) \quad 8.4 \cdot 10^{-17} s$

ejemplo fuerte $\phi^0 (s\bar{s}) \longrightarrow K^+ K^- (u\bar{s}, s\bar{u})$

$$\mu^- \longrightarrow e^- \bar{\nu}_e \nu_\mu \quad 2.2 \cdot 10^{-6} s$$

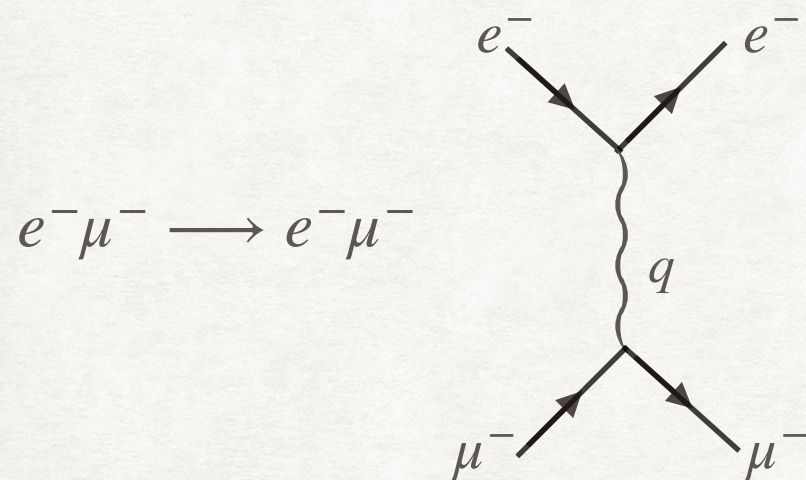
$$n \longrightarrow p e^- \bar{\nu}_e \quad (d \longrightarrow u e^- \bar{\nu}_e)$$

$$p \longrightarrow n e^+ \nu_e \quad (u \longrightarrow d e^+ \nu_e)$$

$$\begin{pmatrix} c \\ s \end{pmatrix} \begin{pmatrix} u \\ d \end{pmatrix} \begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}$$

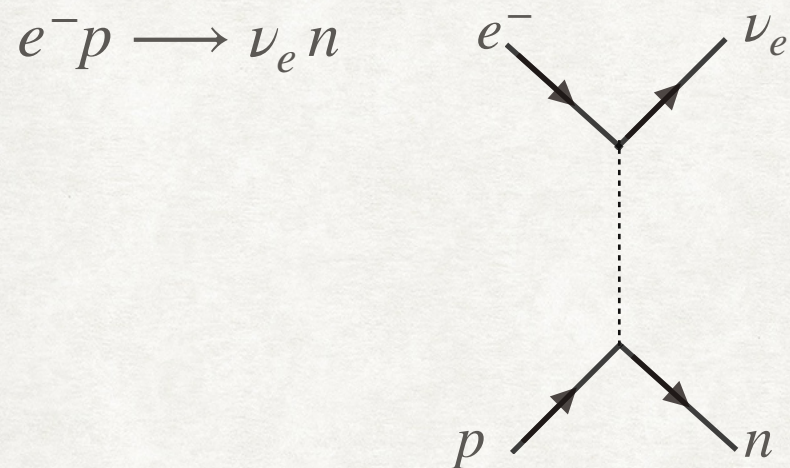
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teoría de Fermi: calcar QED



$$\mathcal{M} \sim \frac{1}{-q^2} J_\rho^{(e^-)} J_\rho^{(\mu^-)}$$

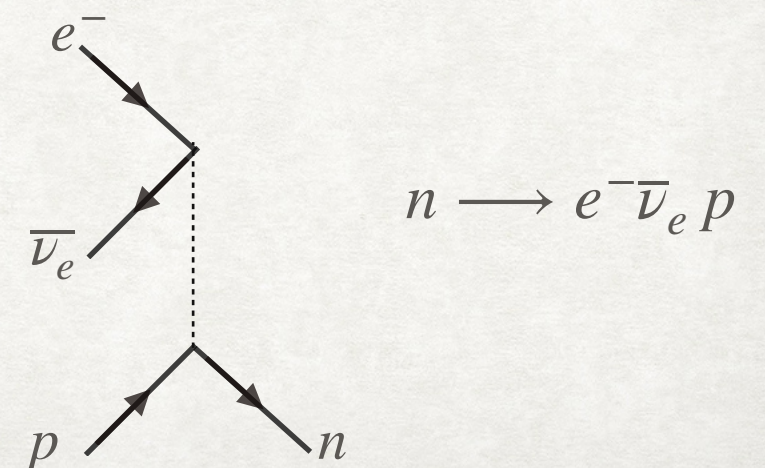
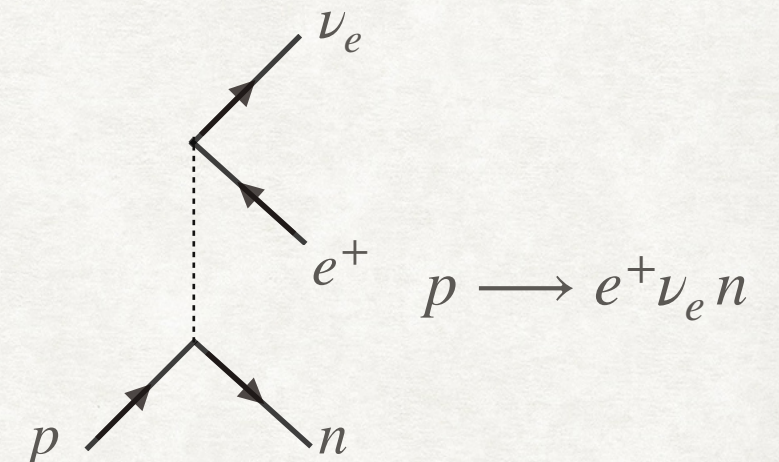
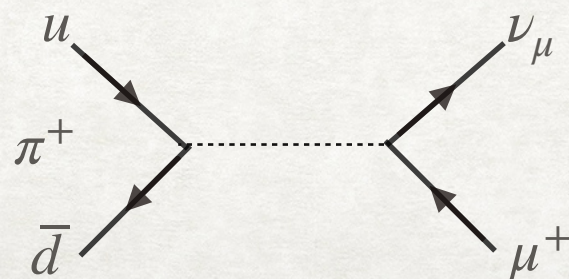
$$\sim \frac{e^2}{-q^2} \bar{u}_e \gamma_\rho u_e \bar{u}_\mu \gamma^\rho u_\mu$$



$$\mathcal{M} \sim G_F J_\rho^{(e^- \nu_e)} J_\rho^{(pn)}$$

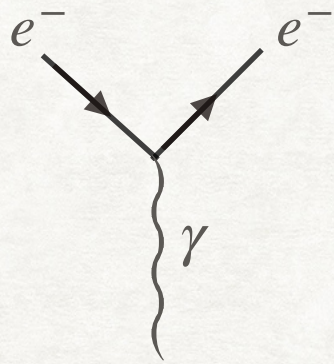
$$\sim G_F \bar{u}_{\nu_e} \gamma_\rho u_e \bar{u}_n \gamma^\rho u_p$$

$$\begin{pmatrix} p \\ n \end{pmatrix} \longrightarrow \begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \longrightarrow \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}$$

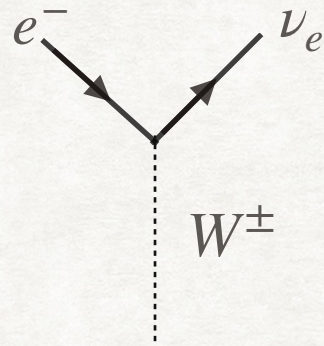


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teoría de Fermi: calcar QED



$$\frac{e^2}{-q^2}$$



$$G_F \sim \frac{g^2}{M_W^2 - q^2}$$

si $M_W \gg q$

$$G_F \simeq \frac{g^2}{M_W^2}$$

si $e^2 \sim g^2$

$$M_W \sim 100 \text{ GeV}$$

violación de paridad: los neutrinos o la interacción?

$$\sigma(\pi^+ \longrightarrow \mu^+ \nu_{\mu L}) \neq 0$$

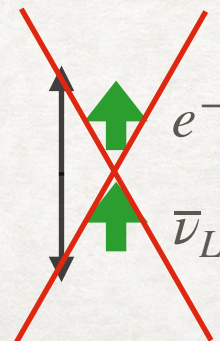
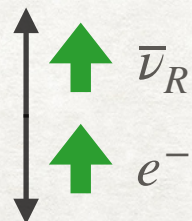
$$\sigma(\pi^+ \longrightarrow \mu^+ \nu_{\mu R}) = 0$$



$J = 5$



$J = 4$

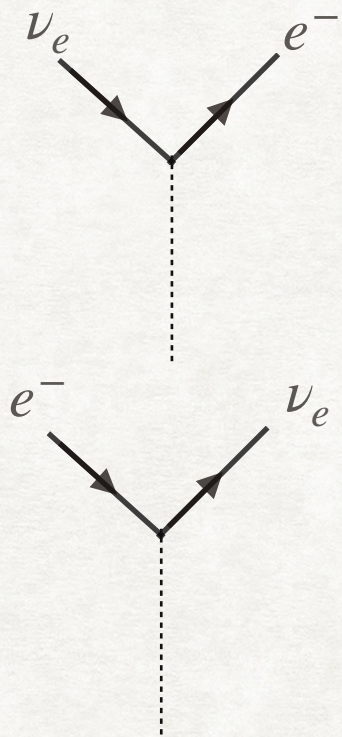


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violación de paridad:



$$J^\mu = \bar{u}_e \gamma^\mu \frac{1}{2}(1 - \gamma^5) u_{\nu_e}$$

$$\begin{aligned} J^\mu &= \bar{u}_{\nu_e} \gamma^\mu \frac{1}{2}(1 - \gamma^5) u_e \\ &= \bar{u}_{\nu_e} \frac{1}{2}(1 + \gamma^5) \gamma^\mu u_e \end{aligned}$$

$$J^\mu \equiv \bar{u}_{\nu_e} \gamma^\mu \frac{1}{2}(1 - \gamma^5) u_e$$

"aumenta" la carga

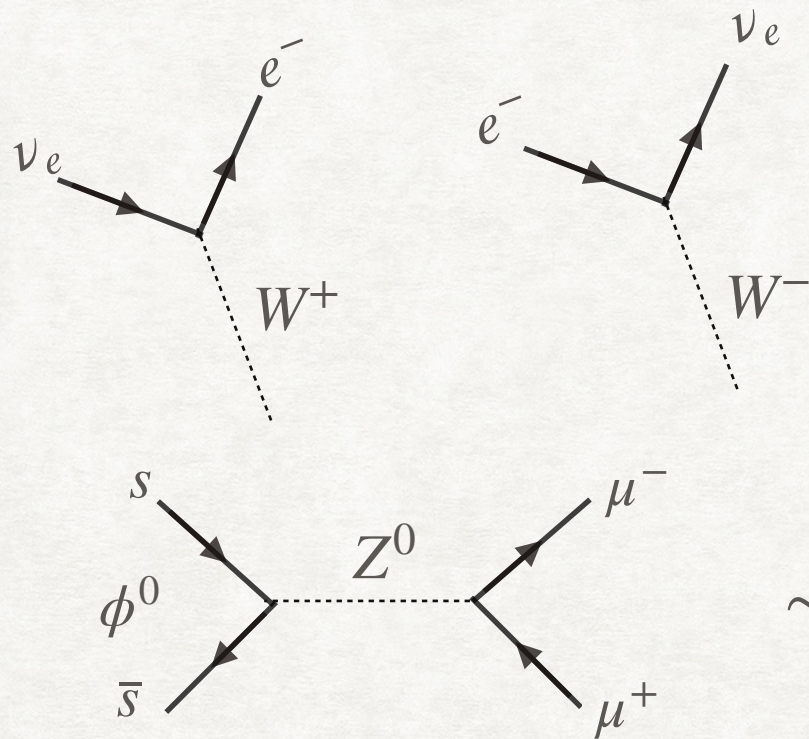
$$J_\mu^\dagger \equiv \bar{u}_e \gamma_\mu \frac{1}{2}(1 - \gamma^5) u_{\nu_e}$$

"disminuye" la carga

$$\mathcal{M} \sim G_F J^\mu J_\mu^\dagger$$

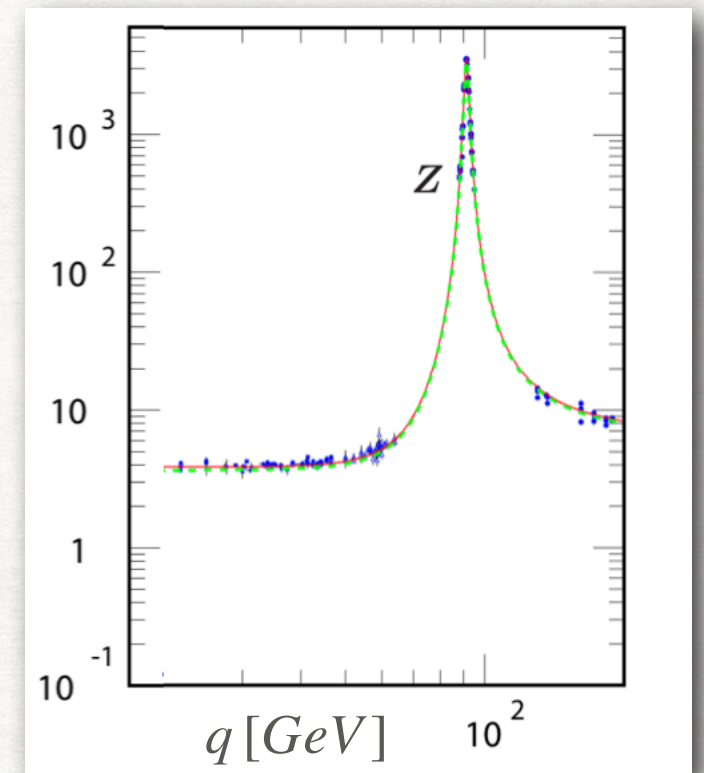
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mediadores neutros:



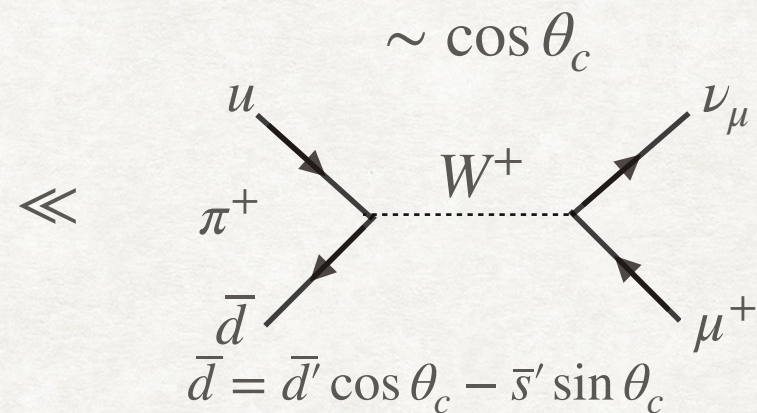
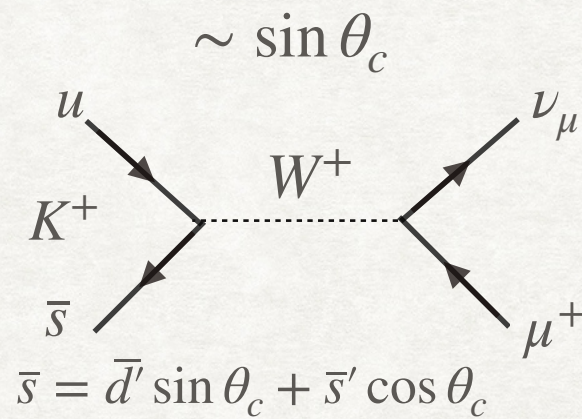
$$\sim \frac{1}{M_Z^2 - q^2}$$

$$M_Z \simeq 91 \text{ GeV}$$



mixing:

$$\begin{pmatrix} \nu_e \\ e^- \end{pmatrix} \quad \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix} \quad \begin{pmatrix} u \\ d \end{pmatrix} \quad \begin{pmatrix} c \\ s \end{pmatrix}$$



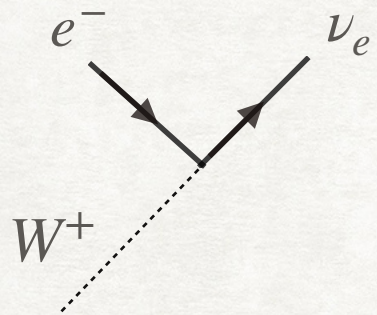
Cabibbo Kobayashi Maskawa

$$\begin{pmatrix} u \\ d' \end{pmatrix} \quad \begin{pmatrix} c \\ s' \end{pmatrix} \quad \begin{cases} d' \equiv d \cos \theta_c + s \sin \theta_c \\ s' \equiv -d \sin \theta_c + s \cos \theta_c \end{cases} \quad \begin{cases} d \equiv d' \cos \theta_c - s' \sin \theta_c \\ s \equiv d' \sin \theta_c + s' \cos \theta_c \end{cases} \quad \begin{matrix} \theta_c \simeq 13^\circ \\ \sin^2 \theta_c \simeq 0.05 \end{matrix}$$

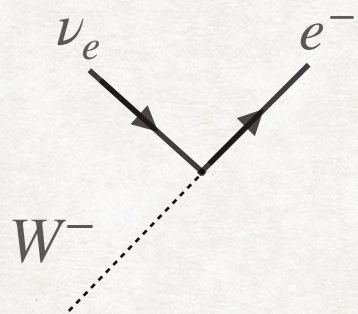
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Gauge SU(2)_L:

$$\Psi_L^e \equiv \begin{pmatrix} \psi_{\nu_{eL}} \\ \psi_{eL} \end{pmatrix} \quad \Psi_L^\mu \equiv \begin{pmatrix} \psi_{\nu_{\mu L}} \\ \psi_{\mu L} \end{pmatrix} \quad \dots \quad \bar{\Psi}_L^e \equiv (\bar{\psi}_{\nu_{eL}}, \bar{\psi}_{eL}) \quad \bar{\Psi}_L^\mu \equiv (\bar{\psi}_{\nu_{\mu L}}, \bar{\psi}_{\mu L}) \quad \dots$$

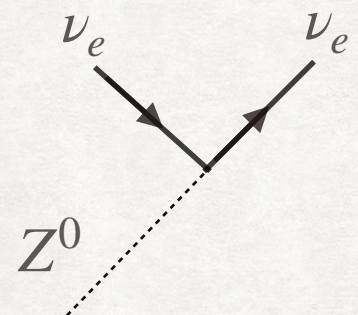


$$J_+^\mu = \bar{\psi}_{\nu_e} \gamma^\mu \frac{1}{2}(1 - \gamma^5) \psi_e = \bar{\psi}_{\nu_{eL}} \gamma^\mu \psi_{eL} = \bar{\Psi}_L^e \gamma^\mu \sigma_+ \Psi_L^e \quad \sigma_+ \equiv \begin{pmatrix} 0 & 1 \\ 0 & 0 \end{pmatrix}$$



$$J_-^\mu = \bar{\psi}_e \gamma^\mu \frac{1}{2}(1 - \gamma^5) \psi_{\nu_e} = \bar{\psi}_{eL} \gamma^\mu \psi_{\nu_{eL}} = \bar{\Psi}_L^e \gamma^\mu \sigma_- \Psi_L^e \quad \sigma_- \equiv \begin{pmatrix} 0 & 0 \\ 1 & 0 \end{pmatrix}$$

$$\sigma_\pm \equiv \frac{1}{2}(\sigma_1 \pm i\sigma_2)$$



$$J_3^\mu = \frac{1}{2} \bar{\psi}_{\nu_{eL}} \gamma^\mu \psi_{\nu_{eL}} - \frac{1}{2} \bar{\psi}_{eL} \gamma^\mu \psi_{eL} = \bar{\Psi}_L^e \gamma^\mu \frac{\sigma_3}{2} \Psi_L^e$$

$$J_i^\mu = \bar{\Psi}_L^e \gamma^\mu \frac{\sigma_i}{2} \Psi_L^e$$

CLASE 15: Interacciones débiles

Gauge $SU(2)_L$:

$$\Psi_L^e \equiv \begin{pmatrix} \psi_{\nu_{eL}} \\ \psi_{eL} \end{pmatrix} \quad \Psi_L^\mu \equiv \begin{pmatrix} \psi_{\nu_{\mu L}} \\ \psi_{\mu L} \end{pmatrix} \quad \dots \quad \bar{\Psi}_L^e \equiv (\bar{\psi}_{\nu_{eL}}, \bar{\psi}_{eL}) \quad \bar{\Psi}_L^\mu \equiv (\bar{\psi}_{\nu_{\mu L}}, \bar{\psi}_{\mu L}) \quad \dots$$

$$\mathcal{L} = \bar{\Psi}_L (i\gamma^\mu \partial_\mu - M) \Psi_L \quad \Psi_L^e \longrightarrow e^{ig\frac{\sigma_i}{2}\alpha_i(x)} \Psi_L^e \quad M \equiv \begin{pmatrix} 0 & 0 \\ 0 & m_e \end{pmatrix} \quad M_W \neq 0 \quad M_{Z^0} \neq 0$$

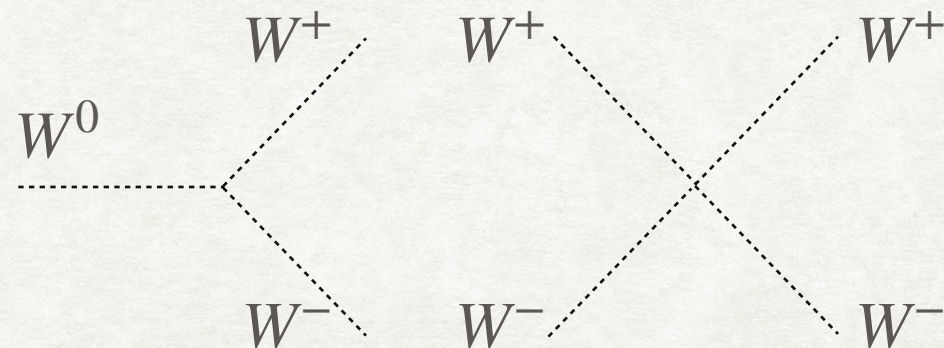
$$D_\mu \equiv \partial_\mu - ig\frac{\sigma_i}{2}W_\mu^i \quad 2^2 - 1 = 3 \quad \text{campos compensadores} \quad W_\mu^\pm \equiv \frac{-1}{\sqrt{2}}(W_\mu^1 \mp iW_\mu^2)$$

$$W^0 \equiv W_\mu^3$$

$$W_\mu^i \longrightarrow W_\mu'^i = \partial_\mu \alpha^i + W_\mu^i - g\epsilon_{ijk}\alpha^j W_\mu^k$$

$$W_{\mu\nu}^i = (\partial_\mu W_\nu^i - \partial_\nu W_\mu^i) + gW_\mu^j W_\nu^k \epsilon_{ijk}$$

$$W_{\mu\nu}^i W_i^{\mu\nu} \sim$$



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Gauge $SU(2)_L$:

lista de problemas:

$M_W \neq 0$ $M_{Z^0} \neq 0$ términos de masa explícitos $\sim M_W^2 W_\mu W^\mu$ romperían la invariancia de gauge

$M \equiv \begin{pmatrix} 0 & 0 \\ 0 & m_e \end{pmatrix}$ términos de masa (distintas) para los fermiones romperían la invariancia de gauge

$W^\pm$ tienen carga eléctrica, cómo interactúan con QED?

hay interacciones débiles sin intercambio de carga entre las componentes R de los quarks