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CP-Violation in the Renormalizable Theory of Weak Interaction

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In a framework of the renormalizable theory of weak interaction, problems of *CP*-violation are studied. It is concluded that no realistic models of *CP*-violation exist in the quartet scheme without introducing any other new fields. Some possible models of *CP*-violation are also discussed.

When we apply the renormalizable theory of weak interaction[1] to the hadron system, we have some limitations on the hadron model. It is well known that there exists, in the case of the triplet model, a difficulty of the strangeness changing neutral current and that the quartet model is free from this difficulty. Furthermore, Maki and one of the present authors (T.M.) have shown[2] that, in the latter case, the strong interaction must be chiral $SU(4) \times SU(4)$ invariant as precisely as the conservation of the third component of the iso-spin I_3. In addition to these arguments, for the theory to be realistic, *CP*-violating interactions should be incorporated in a gauge invariant way. This requirement will impose further limitations on the hadron model and the *CP*-violating interaction itself.

⋮

i) *Case* (A, C)

This is the most natural choice in the quartet model. Let us denote two ($SU_{\text{weak}}(2)$) doublets and four singlets by L_{d1}, L_{d2}, $R_{s1}^{(p)}$, $R_{s2}^{(p)}$, $R_{s1}^{(n)}$ and $R_{s2}^{(n)}$, where superscript $p\,(n)$ indicates p-like (n-like) charge states. In this case, $\mathcal{L}_{\text{mass}}$ takes, in general, the following form:

$$\mathcal{L}_{\text{mass}} = \sum_{i,j=1,2} [M_{ij}^{(n)} \bar{L}_{di} \varphi R_{sj}^{(n)} + M_{ij}^{(p)} \bar{L}_{di} \varepsilon \varphi^* R_{sj}^{(p)}] + \text{h.c.}\,,$$

$$\varphi^* = \begin{pmatrix} \varphi^- \\ \bar{\varphi}^0 \end{pmatrix}, \qquad \varepsilon = \begin{pmatrix} 0 & 1 \\ -1 & 0 \end{pmatrix}, \tag{1}$$

iv) *Case* (A, A)

In a similar way, we can show that no CP-violation occurs in this case as far as $\mathcal{L}'=0$. Furthermore this model would reduce to an exactly $U(4)$ symmetric one.

Summarizing the above results, we have no realistic models in the quartet scheme as far as $\mathcal{L}'=0$. Now we consider some examples of CP-violation through $\mathcal{L}'$. Hereafter we will consider only the case of (A, C). The first one is to introduce another scalar doublet field ψ. Then, we may consider an interaction with this new field

$$\mathcal{L}'=\bar{q}\boldsymbol{\psi}\boldsymbol{C}\frac{1-\gamma_5}{2}q+\text{h.c.}\,, \tag{11}$$

$$\boldsymbol{\psi}\equiv\begin{pmatrix}\bar{\psi}^0 & \psi^+ & 0 & 0\\ -\psi^- & \psi^0 & 0 & 0\\ 0 & 0 & \bar{\psi}^0 & \psi^+\\ 0 & 0 & -\psi^- & \psi^0\end{pmatrix},\qquad \boldsymbol{C}\equiv\begin{pmatrix}c_{11} & 0 & c_{12} & 0\\ 0 & d_{11} & 0 & d_{12}\\ c_{21} & 0 & c_{22} & 0\\ 0 & d_{21} & 0 & d_{22}\end{pmatrix},$$

:

$$\begin{pmatrix}\cos\theta_1 & -\sin\theta_1\cos\theta_3 & -\sin\theta_1\sin\theta_3\\ \sin\theta_1\cos\theta_2 & \cos\theta_1\cos\theta_2\cos\theta_3-\sin\theta_2\sin\theta_3 e^{i\delta} & \cos\theta_1\cos\theta_2\sin\theta_3+\sin\theta_2\cos\theta_3 e^{i\delta}\\ \sin\theta_1\sin\theta_2 & \cos\theta_1\sin\theta_2\cos\theta_3+\cos\theta_2\sin\theta_3 e^{i\delta} & \cos\theta_1\sin\theta_2\sin\theta_3-\cos\theta_2\cos\theta_3 e^{i\delta}\end{pmatrix}. \tag{13}$$

kompleksna faza matrike CKM (za 3 generacije kvarkov) je vir kršitve simetrije CP

$$V_{CKM} = \begin{bmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{bmatrix} + O(\lambda^4)$$

$\lambda \approx 0.225$

$$\Gamma(B^0 \to J/\psi K_S) \propto e^{-t}\left[1 + \frac{1-\left|\lambda_{J/\psi K_S}\right|^2}{1+\left|\lambda_{J/\psi K_S}\right|^2}\cos(xt) - 2\,\mathrm{Im}\left(\frac{\lambda_{J/\psi K_S}}{1+\left|\lambda_{J/\psi K_S}\right|^2}\right)\sin(xt)\right]$$

$$\mathrm{Im}\left(\lambda_{J/\psi K_S}\right) \approx -\sin(2\varphi_{td})$$