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Electroweak Interactions at an Infinite Sublayer Quark Level. III. *CP* Violation

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In a previous paper we proposed the infinite sublayer quark model, in which there exists an infinite number of quarks u_∞ and antiquarks u^c_∞ at an infinite sublayer level. By applying the standard model of the electroweak interactions to the weak isospin doublets $(u_{\infty L}, u^{cp}_{\infty L})^T$ and $(u_{\infty L}, u^{ct}_{\infty L})^T$, it is shown that there exists only one phase factor, which causes *CP* violation.

1. INTRODUCTION

The origin of *CP* violation is still not established in particle physics (Jarlskog, 1989) and new physics will be requried to understand *CP* violation (Georgi, 1984).

Christenson *et al.* (1964) discovered that *CP* was violated in K^0 decay. Shortly after the 1964 experiment it was pointed out by Wolfenstein (1964) that *CP* violation in the K^0 system could be explained by a new superweak interaction of a strength 10^{-9} times that of the standard weak interaction. Weinberg (1976) suggested a model of *CP* violation in which the Higgs bosons did not change flavor, but *CP* violation still occurred as a result of the coupling among a three-Higgs-boson field. Mohapatra and Pati (1975) suggested a model in which *CP* violation could be explained if the gauge interactions were extended to include bosons $W^\pm_R$ interacting with right-handed currents. Kobayashi and Maskawa (1973) proposed a model in which *CP* violation can be incorporated in the standard electroweak theory

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of Glashow (1961), Weinberg (1967), and Salam (1968) if there exist three generations consisting of six quarks.

In the following, we shall show that *CP* violation can be accounted for with only one generation of u and d quarks, by applying the standard model of the electroweak interactions to the infinite sublayer quark model.

2. *CP* VIOLATION AT AN INFINITE SUBLAYER QUARK LEVEL

The infinite sublayer quark model was proposed in a previous paper (Sekine, 1985). This model implies that the proton (p) and the neutron (n) are made of u_1 and d_1 quarks, so that $p = u_1 u_1 d_1$ and $n = u_1 d_1 d_1$. Furthermore, u_1 and d_1 quarks are made of u_2 and d_2, etc. In summary, u_N and d_N quarks at level N are made of u_{N+1} and d_{N+1} quarks at level $N+1$, such as $u_N = (u_{N+1}, u_{N+1}, d_{N+1})$ and $d_N = (u_{N+1}, d_{N+1}, d_{N+1})$, where $N = 1, 2, 3, \ldots, \infty$. Here the u_N and d_N quarks have quantum numbers of spin $J = 1/2$, baryon number $B = 1/3^N$, isospin $I = 1/2$, third component of isospin $I_3 = \pm 1/2$, and fractional electric charge $Q = [(1 \pm 3^N)/(2 \times 3^N)]|e|$, where $|e|$ is the electron charge. Thus, at $N = \infty$, an infinite number of pointlike quarks (u_∞) and antiquarks ($u_\infty^c = d_\infty$) is considered as constituting the nucleon. The superscript c means charge conjugation. The ultimate particle u_∞ has quantum numbers of $J = 1/2$, $I = 1/2$, $I_3 = 1/2$, and $Q = (1/2)|e|$. Thus, all quantum numbers of the u_∞ quark are just one-half and this fermion will behave as if it were a lepton, since the baryon number approaches zero at an infinite sublayer level.

To account for *CP* violation, we shall apply the electroweak model to the interactions at the infinite sublayer quark level.

Consider the quantum numbers of weak isospin $t_3 = 1/2$ and $t_3 = -1/2$ for the ultimate particles $u_{\infty L}$ and $u_{\infty L}^{cp}$, where $u_{\infty L}^{cp}$ means the left-handed particle operated upon by charge conjugation c and then by parity p, viz.,

$$u_{\infty L}^{cp} \equiv \gamma^0 C \gamma^0 (1/2)(1 - \gamma_5) u_\infty^* \tag{1}$$

At the infinite sublayer quark level, the hypercharge of $u_{\infty L}$ and $u_{\infty L}^{cp}$ quarks becomes zero by applying the Nishijima–Gell-Mann relation to weak quantum numbers. Furthermore, we assume that $u_{\infty L}$ and $u_{\infty L}^{cp}$ quarks are massless.

Now we consider the doublet $\chi = (u_{\infty L}, u_{\infty L}^{cp})^T$, where the superscript T means transposed. Then the Lagrangian describing the electroweak interactions is written as follows:

$$L = \bar{\chi} \gamma^\mu [i\partial_\mu - (g/2)\tau \cdot \mathbf{W}_\mu] \chi \tag{2}$$

where g is the coupling constant. $\mathbf{W}_\mu$ are three gauge fields of $SU(2)_L$, and $\tau/2$ are generators of $SU(2)_L$. The Lagrangian in equation (2) is invariant under the following infinitesimal gauge transformation:

$$\chi' = [1 + i(g/2)\boldsymbol{\alpha}\cdot\boldsymbol{\tau}]\chi \tag{3}$$

where $\boldsymbol{\alpha}$ are parameters in $SU(2)_L$. Thus, we obtain

$$u'_{\infty L} = [1 + i(g/2)\alpha^3]u_{\infty L} + i(g/2)(\alpha^1 - i\alpha^2)u^{cp}_{\infty L} \tag{4}$$

$$u^{cp'}_{\infty L} = i(g/2)(\alpha^1 + i\alpha^2)u_{\infty L} + [1 - i(g/2)\alpha^3]u^{cp}_{\infty L} \tag{5}$$

However, $u_{\infty L}$ and $u^{cp}_{\infty L}$ are not independent of each other; therefore, $u^{cp'}_{\infty L}$ should be equal to the CP transformation of $u'_{\infty L}$, that is, $u'^{cp}_{\infty L}$. From equation (4), we obtain

$$\begin{aligned} u^{cp'}_{\infty L} &\equiv u'^{cp}_{\infty L} \\ &= [1 - i(g/2)\alpha^3]u^{cp}_{\infty L} + i(g/2)(\alpha^1 + i\alpha^2)u_{\infty L} \end{aligned} \tag{6}$$

Equation (6) is quite the same as equation (5). Therefore, the weak isospin doublet $(u_{\infty L}, u^{cp}_{\infty L})^T$ does not give any limitations to the parameters $\boldsymbol{\alpha}$ under the condition that $u_{\infty L}$ and $u^{cp}_{\infty L}$ are not independent of each other. Thus, we can conclude that the standard model of the electroweak interactions holds even at an infinite sublayer quark level, insofar as we consider the weak isospin doublet $(u_{\infty L}, u^{cp}_{\infty L})^T$ (Okamato *et al.*, 1992). Similarly, the doublet $(u_{\infty L}, u^{ct}_{\infty L})^T$ can be explained within the framework of the standard model of the electroweak interactions, where $u^{ct}_{\infty L}$ means the left-handed particle operated upon by charge conjugation c and then time reversal t.

Now we consider the isospin doublets $(u_{\infty L}, u^{cp'}_{\infty L})^T$ and $(u_{\infty L}, u^{ct'}_{\infty L})^T$, from which we can construct the Lagrangian. Here we have

$$\begin{pmatrix} u^{cp'}_{\infty L} \\ u^{ct'}_{\infty L} \end{pmatrix} = U \begin{pmatrix} u^{cp}_{\infty L} \\ u^{ct}_{\infty L} \end{pmatrix} \tag{7}$$

where U is the unitary matrix. That is, the second component of χ of the Lagrangian in equation (2) is a linear combination of $u^{cp}_{\infty L}$ and $u^{ct}_{\infty L}$. Since $u^{cp}_{\infty L}$ and $u^{ct}_{\infty L}$ are dependent on each other, the unitary matrix U is restricted to the form

$$U = \begin{pmatrix} \cos\theta & \pm i\sin\theta \\ \pm i\sin\theta & \cos\theta \end{pmatrix} e^{i\delta} \tag{8}$$

It is important to note that the phase factor $e^{i\delta}$ cannot be eliminated by redefining the phase of $u_{\infty L}$, as shown in the following. Suppose that θ in equation (8) is zero for the sake of simplicity; then $u^{cp'}_{\infty L} = e^{i\delta}u^{cp}_{\infty L}$ and the isospin doublet becomes $(u_{\infty L}, e^{i\delta}u^{cp}_{\infty L})^T$. If $u_{\infty L}$ and $u^{cp}_{\infty L}$ are independent of each other, it is possible to redefine $u_{\infty L}$ as $e^{i\delta}u_{\infty L}$, while $u^{cp}_{\infty L}$ remains unchanged, and hence the obtained isospin doublet $e^{i\delta}(u_{\infty L}, u^{cp}_{\infty L})^T$ gives the same Lagrangian as the original one of the doublet $(u_{\infty L}, u^{cp}_{\infty L})^T$. In our arguments, however, $u^{cp}_{\infty L}$ is uniquely determined by $u_{\infty L}$, so that the redefinition of $u_{\infty L}$ means a change in $u^{cp}_{\infty L}$. Therefore, the phase factor $e^{i\delta}$ cannot be eliminated.

It is well known that the presence of phase factors that cannot be eliminated results in *CP* violation. Kobayashi and Maskawa required three isospin doublets consisting of six quarks to construct an uneliminated phase factor. Here, we need two doublets ($\theta \neq 0$) or even one doublet ($\theta = 0$) to obtain such a phase factor.

3. CONCLUSIONS

We considered the doublets $(u_{\infty L}, u^{cp}_{\infty L})^T$ and $(u_{\infty L}, u^{ct}_{\infty L})^T$ which can be explained within the framework of the standard model of the electroweak interactions. In these doublets, the phase factor inevitably remains and hence *CP* is violated. Furthermore, even if we consider only one doublet, *CP* is violated. Finally, it is of interest to speculate that *CP* violation at the infinite sublayer quark level may be related to *CP* violation in the origin of the universe accounting for the asymmetry of the number of particles and antiparticles in the present universe.

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