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DYNAMICAL ANALOGY OF CABIBBO — KOBAYASHI — MASKAWA MATRICES

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I. INTRODUCTION

The theory of electroweak interactions, at the present time, has the status of a theory which is confirmed with a high degree of precision. However, some experimental results (the existence of quarks and of leptons families, etc.) did not get any explanation in the framework of the theory. One such part of the electroweak theory is existence of quark mixing which is introduced by the Cabibbo — Kobayashi — Maskawa matrices (i.e., these matrices are used for parametrization of the quark mixing).

In this work a dynamical mechanism of quark mixing by the use of doublets of massive vector carriers of weak interaction $B^{\pm}$, $C^{\pm}$, $D^{\pm}$ is suggested, i.e., expansion of the electroweak theory is proposed, where together with the $W^{\pm}$, Z^0 bosons there arise three doublets of massive vector carriers of the weak interaction $B^{\pm}$, $C^{\pm}$, $D^{\pm}$ leading to the quark mixing. An estimation of the boson masses and the quasielastic reactions proceeding through these bosons are given.

II. DYNAMICAL ANALOGY OF THE CABIBBO MATRIX

The charged current [1] in the standard theory of weak interaction has the form

$$j_F^{\mu} = \left|\bar{u}\,\bar{c}\right|_L \gamma^{\mu} V \left|\begin{matrix} d \\ s \end{matrix}\right|_L ,$$

$$V = \left|\begin{matrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{matrix}\right| , \qquad (1)$$

where V [2] characterizes mixing of the d and s quarks:

$$\left|\begin{matrix} d' \\ c' \end{matrix}\right| = V \left|\begin{matrix} d \\ c \end{matrix}\right| . \qquad (2)$$

This mixing of the quarks is not connected with the weak interaction (i.e., with $W^{\pm}$ and Z^0 bosons exchange). From equation (1) it is well seen that mixing of the d, s quarks and exchange of $W^{\pm}$, Z^0-bosons take place in an independent manner (i.e., if the matrix V were diagonal, mixing of the d and s quarks would not take place).

If the mechanism of this mixing is realized independently of the weak interaction ($W^{\pm}$, Z^0-boson exchange) with a probability determined by the mixing angle θ, then this violation could be found in the strong and electromagnetic interactions of the quarks as a clear violation of the isospin and strangeness conservation. But the available experimental results show that there is no clear violation of the quantum number conservation in the strong and electromagnetic interactions of the quarks. Then we must connect the non-conservation of isospin and strangeness (or mixing of d and s quarks) with some type of interaction mixing of the quarks. We can do it introducing together with $W^{\pm}$, Z^0-bosons the heavier vector bosons $B^{\pm}$ which interact with the d and s quarks with violation of isospin and strangeness conservation. The corresponding current can be chosen in the following form:

$$j^{\mu} = \left|\bar{u}\,\bar{c}\right|_L \gamma^{\mu} \left|\begin{matrix} 0 & 1 \\ -1 & 0 \end{matrix}\right| \left|\begin{matrix} d \\ s \end{matrix}\right|_L . \qquad (3)$$

Equation (1) at $\theta = 0$ (i.e., without taking into account the quark mixing) will have the form

$$j_F'^{\mu} = \left|\bar{u}\,\bar{c}\right|_L \gamma^{\mu} \left|\begin{matrix} 1 & 0 \\ 0 & 1 \end{matrix}\right| \left|\begin{matrix} d \\ s \end{matrix}\right|_L . \qquad (4)$$

Combining (3) and (4) and performing normalization of the amplitudes of probability for the existence of quarks in an appropriate manner we come to an equation of the same type as (1) when the square momentum transfer $q^2 \ll m_W^2$. In this equation the mixing angle θ can be expressed through the $W^{\pm}$, $B^{\pm}$ masses and the charges G_B, G_W:

$$\mathrm{tg}\,\theta \cong \frac{m_W^2 G_B}{m_B^2 G_W} . \qquad (5)$$

If $G_B \cong G_W$, then $\mathrm{tg}\,\theta \cong \dfrac{m_W^2}{m_B^2}$.

In the above approach a neutral boson, B^0, may appear together with $B^{\pm}$. If we proceed from the analogy to the standard theory of electroweak interactions or to chromodynamics, then besides B^0 there must exist a scalar boson — B'^0, which will be mixed with B^0. If the mass of B'^0 is sufficiently large, then, due to mixing with this boson, B^0 will acquire a large mass and, as a result, processes involving the participation of neutral currents

$$j^{\mu} = |\bar{d}\,\bar{s}|_L \gamma^{\mu} \begin{vmatrix} 0 & 1 \\ -1 & 0 \end{vmatrix} \begin{vmatrix} d \\ s \end{vmatrix}_L \quad (6)$$

will be strongly suppressed.

However, owing to the u and c quarks having different masses corresponding processes will proceed via the GIM mechanism [3].

As a matter of fact, the analogy with the theory of electroweak interaction and chromodynamics may not take place; then, if to be strict, we must take into account only the $B^{\pm}$ bosons.

III. DYNAMICAL ANALOGY OF THE KOBAYASHI — MASKAWA MATRIX

Now let us go to generalization of the above-considered scheme of two families of quarks to the case of three quark families.

In the case of three families of quarks a generalization of the Cabibbo matrix (1) is given by the Kobayashi — Maskawa matrix [4]:

$$J^{\mu} = |\bar{u}\,\bar{c}\,\bar{t}|_L \gamma^{\mu} V \begin{vmatrix} d \\ s \\ b \end{vmatrix}_L ,$$

$$V = \begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix} . \quad (7)$$

We shall choose a parametrization of the matrix V in the form suggested by Maiani [5] (we shall not consider CP-violation and therefore shall assume $\delta = 0$):

$$V = \begin{vmatrix} 1 & 0 & 0 \\ 0 & c_{\gamma} & s_{\gamma} \\ 0 & -s_{\gamma} & c_{\gamma} \end{vmatrix} \begin{vmatrix} c_{\beta} & 0 & s_{\beta} \\ 0 & 1 & 0 \\ -s_{\beta} & 0 & c_{\beta} \end{vmatrix} \begin{vmatrix} c_{\theta} & s_{\theta} & 0 \\ -s_{\theta} & c_{\theta} & 0 \\ 0 & 0 & 1 \end{vmatrix} , \quad (8)$$

$$c_{\theta} = \cos\theta, \qquad s_{\theta} = \sin\theta.$$

To the nondiagonal terms (which are responsible for mixing of the d, s, b-quarks in the three matrices) in (8) we shall make correspond three doublets of vector bosons $B^{\pm}, C^{\pm}, D^{\pm}$, whose contributions are parametrized by three angles θ, β, γ (when $q^2 \ll m_W^2$):

$$\mathrm{tg}\,\theta \cong \frac{m_W^2 G_B}{m_B^2 G_W}, \qquad \mathrm{tg}\,\beta \cong \frac{m_W^2 G_C}{m_C^2 G_W}, \qquad \mathrm{tg}\,\gamma \cong \frac{m_W^2 G_D}{m_D^2 G_W}. \quad (9)$$

If $G_{B^{\pm}} \cong G_{C^{\pm}} \cong G_{D^{\pm}} \cong G_{W^{\pm}}$, then

$$\mathrm{tg}\,\theta \cong \frac{m_W^2}{m_B^2}, \qquad \mathrm{tg}\,\beta \cong \frac{m_W^2}{m_C^2}, \qquad \mathrm{tg}\,\gamma \cong \frac{m_W^2}{m_D^2}. \quad (10)$$

Concerning the neutral vector bosons B^0, C^0, D^0, the neutral scalar bosons B'^0, C'^0, D'^0 and the GIM mechanism we can repeat the same arguments which were given in the preceding section.

IV. REACTIONS PROCEEDING THROUGH THE $B^{\pm}, C^{\pm}, D^{\pm}$ BOSONS AND ESTIMATION OF THEIR MASSES

The reactions with substitution $d \leftrightarrow s, d \leftrightarrow b, s \leftrightarrow b$ proceed via the $B^{\pm}, C^{\pm}, D^{\pm}$-bosons. Besides the decays leptons and hadrons, the following quasielastic reactions proceed through the exchange of the bosons:

$$\text{a) } u + d \xrightarrow{B} u + s, \quad p + p \longrightarrow p + \Sigma^{+},$$
$$\nu(\bar{\nu}) + \bar{e}(e) \xrightarrow{B} u(\bar{u}) + \bar{s}(s);$$
$$\text{b) } u + d \xrightarrow{C} u + b, \quad p + p \longrightarrow p + \Sigma^{+}(q_b),$$
$$\nu(\bar{\nu}) + \bar{e}(e) \xrightarrow{C} u(\bar{u}) + \bar{b}(b);$$
$$\text{c) } c + s \xrightarrow{D} c + b,$$
$$\nu(\bar{\nu}) + \bar{e}(e) \xrightarrow{D} c(\bar{c}) + \bar{b}(b). \quad (11)$$

Let us estimate the masses of the $B^{\pm}, C^{\pm}, D^{\pm}$-bosons. For this purpose we shall use the data from [6] and equation (10):

1) $\mathrm{tg}\,\theta \cong 0.218 \div 0.224$,

$m_{B^{\pm}} \cong 169.5 \div 171.8$ GeV;

2) $\mathrm{tg}\,\beta \cong 0.032 \div 0.054$,

$m_{C^{\pm}} \cong 345.2 \div 448.4$ GeV;

3) $\mathrm{tg}\,\gamma \cong 0.002 \div 0.007$,

$m_{D^{\pm}} \cong 958.8 \div 1794$ GeV. (12)

V. CONCLUSION

A dynamical analogy of the Cabibbo — Kobayashi — Maskawa matrices is proposed. For this purpose three doublets of vector bosons $B^{\pm}, C^{\pm}, D^{\pm}$ are introduced. Estimation of their masses ($m_B \cong 170$ GeV, $m_C \cong 345$ GeV, $m_D \cong$ $\cong 1000$ GeV) is performed. The quasielastic reactions proceeding through the exchange of these bosons are listed.

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Динамический аналог
матриц Кабиббо — Кобаяши — Маскавы

Строится динамический аналог матриц Кабиббо — Кобаяши — Маскавы. Т.е. предлагается расширение теории слабого взаимодействия с включением в нее трех дублетов векторных бозонов $B^{\pm}, C^{\pm}, D^{\pm}$, приводящих к смешиванию кварков. Даются оценки масс этих бозонов и квазиупругие реакции, которые протекают через обмен этих бозонов.

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Dynamical Analogy
of Cabibbo — Kobayashi — Maskawa Matrices

The dynamical analogy of Cabibbo — Kobayashi — Maskawa matrices is built. I.e. the expansion of the weak interaction theory with the inclusion of three doublets of the vector bosons $B^{\pm}, C^{\pm}, D^{\pm}$, leading to the quarks mixing is suggested. Estimation of the bosons masses is performed. The quasielastic processes proceeding through exchange of the bosons are given.

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