Oscillations of *CP* violation in the "horizontal" superweak gauge scheme

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A model, in the context of which the *CP* violation, the neutral-meson oscillations and other rare processes are attributable to superweak, horizontal interactions, is analyzed.

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The arrangement of quarks and leptons in generations $(u, d, \ldots; \nu_e, e^-, \ldots)$, $(c, s, \ldots; \nu_\mu, \mu^-, \ldots)$ (Ref. 1) favors the existence of a horizontal symmetry which unifies these families. We shall examine a scheme which is based on the gauge group $SU(N)^H_L \times SU(N)^H_R \times SU(2)^W_L \times SU(2)^W_R \times U(1) \times SU(3^{\text{color}})$ [where N is the number of generations, and the indices $H(W)$ correspond to the horizontal (weak) symmetry].

1. We write the Lagrangian of the weak and horizontal interactions, which is invariant with respect to this transformation group

$$L_{int} = g\left\{\left[(\bar{\psi}^i_\alpha)_L \gamma_\mu \left(\frac{\lambda^{ij}_L}{2}\,\delta_{\alpha\beta}\right)(\psi^j_\beta)_L\right] Z^k_{L\mu} + \left[(\bar{\psi}^i_\alpha)_L \gamma_\mu \times \left(\frac{\tau^{\alpha\beta}_a}{2}\,\delta_{ij}\right)(\psi^j_\beta)_L\right] W^a_{L\mu}\right\} + (L \to R) + g'\bar{\psi}\gamma_\mu \frac{Y^B}{2}\psi B_\mu, \tag{1}$$

where $\lambda_k/2$ $(k = 1, 2, \ldots, N^2 - 1)$ are the generators of the SU (N) group, τ_a $(a = 1, 2, 3)$ are the Pauli matrices, $\psi^1 = \binom{u}{d}$, $\psi^2 = \binom{c}{s}, \ldots$; $Z^k_{L(R)\mu}$ are the horizontal gauge fields, $W^a_{L(R)\mu}$ are the weak gauge fields, Y^B is the hypercharge of the $U^Y(1)$ group, and B_μ is the corresponding gauge field.

2. The appearance of nonvanishing hadron (lepton) mixing angles in this approach can be accounted for by the current matrix $O^c_{L(R)} = V_{L(R)} U^+_{L(R)} \neq 1$, where $V_{L(R)}$ $(U_{L(R)})$ are the rotation matrices in the "down" space and $Q = -\frac{1}{3}$ ("up," $Q = +\frac{2}{3}$) are those of quarks which diagonalize the hadron mass matrix. The current matrices $U_{L(R)}(\lambda_k/2)U^+_{L(R)}$ and $V_{L(R)}(\lambda_k/2)V^+_{L(R)}$ in this case appear in the horizontal sector of the Lagrangian (1). Within the context of the scheme with two generations of quarks and leptons the matrices $V_{L(R)}$ and $U_{L(R)}$ have the simplest form

$$V = \begin{pmatrix} c_d & s_d \\ -s_d & c_d \end{pmatrix}, \quad U = \begin{pmatrix} c_u & s_u \\ -s_u & c_u \end{pmatrix},$$

where $s_{d(u)}$ $(c_{d(u)}) \equiv \sin\theta_{d(u)}$ $(\cos\theta_{d(u)})$; here $\theta_u - \theta_d = \theta_c$, where θ_c is the Cabibbo angle. To shorten the calculations, we shall limit ourselves to the analysis of this case ($N=2$).

3. Spontaneous symmetry violation is caused by the introduction into the theory of scalar-field multiplets which realize the representations corresponding to the gauge group $SU(2)^H_L \times SU(2)^H_R \times SU(2)^W_L \times SU(2)^W_R \times U(1)$ and which apparently can be divided into two classes: a) a class which determines the mass matrix of the fermion fields of matter

$$\phi\ (2, \bar{2}, 0,0,0), \quad \xi\ (0,0,2,\bar{2},0)$$

and b) a class which determines the masses of the gauge fields

$$\Phi_L\ (3, 1, 0, 0, 0), \ \Phi_R\ (1, 3, 0, 0, 0), \ \chi_L\ (0, 0, 3, 1, 1), \ \chi_R\ (0, 0, 1, 3, 1),$$

$$\kappa_L\ (2, 1, 0, 0, 0), \ \kappa_R\ (1, \bar{2}, 0, 0, 0), \ \eta_L\ (0, 0, 2, 1, 1) \text{ and } \eta_R\ (0, 0, 1, \bar{2}, 1).$$

The following analysis of the scheme under consideration involves the standard procedures of constructing and diagonalizing the mass matrix of the "horizontal" gauge fields. As a result, the physical states of the gauge fields Z^k can be determined from the relation

$$H^i_{\mu L(R)} = a^{ik}_{L(R)} Z^k_{\mu L(R)} ,$$

where a is an orthogonal matrix of the form

$$a = \begin{pmatrix} c_1 & -s_1 c_2 & -s_1 s_2 \\ s_1 & c_1 c_2 & c_1 s_2 \\ 0 & s_2 & -c_2 \end{pmatrix},$$

$$s_1 = \frac{\beta_1}{\sqrt{r^2 + |\beta|^2}}, \quad c_1 = \frac{\sqrt{a^2 + \beta_2^2}}{\sqrt{a^2 + |\beta|^2}}, \quad s_2 = \frac{a}{\sqrt{a^2 + \beta_2^2}}, \quad c_2 = \frac{\beta_2}{\sqrt{a^2 + \beta_2^2}},$$

where $\beta_1 \equiv \mathrm{Re}\,\beta$, $\beta_2 \equiv \mathrm{Im}\,\beta$, and $\langle\Phi\rangle = \begin{pmatrix} \alpha & \beta \\ \beta^* & -\alpha \end{pmatrix}$ is the vacuum expectation value of the fields Φ.

The masses of the gauge bosons $H^{1,2,3}_\mu$ turn out to be equal to $m_1 = m_3 = 1/\sqrt{2}g \sqrt{k^2 + \alpha^2 + \beta_1^2 + \beta_2^2}$ and $m_2 = 1/\sqrt{2}\,gk$, respectively, where $k = |y_1|^2 + |y_2|^2$ and $\langle\kappa\rangle = (y_1, y_2)$.

4. The violation of CP symmetry in this scheme, which is accomplished in a spontaneous, "soft" way, occurs in the presence of the mass difference of the "horizontal" vector bosons: $m_i - m_j \neq 0$, $(i \neq j)$, $i, j = 1, 2, 3$. The appearance of the current product with different CP parities in the effective Lagrangian is associated with a transition to the physical states of quarks. In fact, we note the following correspondence:

$J_{\mu 1} J_{\mu 2}$; $J_{\mu 2} J_{\mu 3} \to CP = -1$; $J_{\mu i}\, J_{\mu i}$ $(i = 1, 2, 3)$, $J_{\mu 1} J_{\mu 3} \to CP = +1$,
where

$$J_{\mu i} = (\bar{d}\bar{s})_{L(R)}\, \gamma_\mu V_{L(R)} \frac{\lambda^i}{2} V^+_{L(R)} \begin{pmatrix} d \\ s \end{pmatrix}_{L(R)}$$

$$+ \; (\bar{u}\bar{c})_{L(R)}\, \gamma_\mu U_{L(R)} \frac{\lambda^i}{2} U^+_{L(R)} \begin{pmatrix} u \\ c \end{pmatrix}_{L(R)}.$$

5. Using the results obtained above, we can easily calculate the possible contribution of the horizontal interactions to the parameters of the rare processes observed experimentally. We write here, for example, the expressions for the parameters that characterize the mixing and CP violation in the K- and D-meson systems

$$\left(\frac{\Delta m_k}{m_k}\right)_H = \frac{2}{3} \frac{G_F}{\sqrt{2}} f_k^2\, \Delta [(c_1^2 - s_1^2) c_2^2 + \sin^2 2\,\theta_d (c_2^2 s_2^2 - s_1^2) - \sin 4\theta_d\, s_1 s_2 c_2) ,$$

$$\left(\frac{\Delta mD}{mD}\right)_H = \begin{cases} \theta_d \to \theta_u \\ f_k \to f_D \end{cases} \tag{2}$$

$$\left(\frac{\mathrm{Im}\, m_{12}^k}{m_k}\right)_H = \frac{4}{3} \frac{G_F}{\sqrt{2}} f_k^2\, \Delta [c_1 c_2 (s_1 c_2 \cos 2\,\theta_d - s_2 \sin 2\theta_d)],$$

$$\left(\frac{\mathrm{Im}\, m_{12}^D}{m_D}\right)_H = \begin{cases} \theta_d \to \theta_u \\ f_k \to f_D \end{cases} ,$$

where

$$\Delta = \frac{m_W^2}{m_1^2}\left(1 - \frac{m_1^2}{m_2^2}\right).$$

6. We shall discuss the most important physical effects for which this scheme is responsible: 1) The CP violation is associated solely with the horizontal superweak processes; 2) there are constraints imposed on the gauge-boson masses: H_i $(i = 1, 2, 3)$ $m_{H_i} \gtrsim 10^4$ GeV, which follow from the experimental data for the processes $K_L^0 \to \bar{\mu} e\, (\mu \bar{e})$; 3) the search for horizontal interactions apparently should be concentrated on the D^0, $\bar{D}^0$ system. This is a consequence of the fact that the contribution of the weak interactions to the processes $D^0 \longleftrightarrow \bar{D}^0$ is suppressed [$\rho_D^{\exp} < 0.025$ (Ref. 2), $\rho_D^{\text{theor}} \sim 10^{-7}$ (Ref. 3), where ρ is the mixing parameter of a K^0, $\bar{K}^0$ system, $\rho = [(\Delta m)^2 + (\Delta\Gamma/2)^2] / [2\Gamma^2 + (\Delta m)^2 - (\Delta\Gamma/2)^2]$ for a comparison: $\rho(K^0)_{\exp} \approx 0.5$].

The new type of interactions can therefore appear without a background from the ordinary weak processes at the level that can be attained in the present-day experiments.[2] We should also emphasize that the horizontal interactions can saturate the experimental upper limit $\rho_D < 0.025$ (or $\Delta m_D/m_D < 10^{-12}$), which is accompanied by the maximum CP violation [$a_D \sim 1$, for example, for $s_1 = 0$, $s_2^2 \approx 0.2$, $\Delta \sim 10^{-7}$, see Eq. (2), where a_D is the charge asymmetry in the semileptonic decay modes of D^0, $\bar{D}^0$ mesons]. This is particularly important in the light of the open question concerning the nature of *CP*-symmetry violation.

In this letter we would also like to focus attention on the fact that an increase in the statistics above the present-day experimental level[2] in the experiments involving the study of the D^0, $\bar{D}^0$ system in the e^+e^- rings

$$e^+ e^- \to \gamma \to D^0,\ \bar{D}^0 \to l^{\mp} \bar{\nu}_l\ (\nu_l)\ X^{\pm}$$
$$\hookrightarrow l^{\pm} \nu_l\ (\bar{\nu}_l)\ X^{\mp}$$

[where l are leptons, and (e, μ) and $X^{\pm}$ are hadrons] could lead to the detection of oscillations $D^0 \longleftrightarrow \bar{D}^0$ which occur, for example, with a maximum CP violation; this would show that these processes are superweak.

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