Weak interaction in the three-triplet model of integer-charge quarks

Dzh. L. Chkareuli

Physics Institute, Georgian Academy of Sciences

(Submitted June 11, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **24**, No. 4, 243–246 (20 August 1976)

An $SU(2)\otimes U(1)$ gauge theory of weak interaction with right-helicity "colored" currents is constructed in the Han-Nambu quark model. The new currents lead to octet enhancement in nonleptonic decays of kaons and hyperons and predict the appearance of the dimuons observed in the Batavia neutrino experiments.

PACS numbers: 11.30.Jw, 11.30.Qc, 12.30.Cx

We assume the hypothesis that color (colored $SU(3)$ symmetry) is not conserved in weak and electromagnetic interactions, and that all hadrons are made up of 9 Han-Nambu quarks[1,2]:

  216

$$q = \begin{pmatrix} p_1 & p_2 & p_3 \\ n_1 & n_2 & n_3 \\ \lambda_1 & \lambda_2 & \lambda_3 \end{pmatrix} ; \qquad Q = \begin{pmatrix} 1 & 1 & 0 \\ 0 & 0 & -1 \\ 0 & 0 & -1 \end{pmatrix} \tag{1}$$

and consider the possibility of modification of the weak hadron current by terms from the sector of the "colored" currents in model (1), for the purpose of analyzing the new data in lepton-hadron processes,[3-5] which turn out the outside the scope of the predictions of the ordinary Weinberg-Salam 4-quark theory.[6]

By assumption, quarks from doublets and singlets relative to the "weak" $SU(2)\otimes U(1)$ gauge group:

$$\begin{pmatrix} p_3 & n_2 \\ n_3(\theta) & \lambda_3(\theta) \end{pmatrix}_L , \quad \begin{pmatrix} n_1 & \lambda_2 \\ n_3(\theta') & \lambda_3(\theta') \end{pmatrix}_R \tag{2}$$

($n_3(\theta) = n_3 \cos\theta + \lambda_3 \sin\theta$, $\lambda_3(\theta) = -n_3 \sin\theta + \lambda_3 \cos\theta$, θ is the Cabibbo angle); the rest form singlets. The structure of the doublets is such as to ensure the Glashow-Iliopulos-Maiani mechanism[6] for the neutral component of the quark current. We have put in (2) $\theta_1 = \theta_2 = 0$ and $\theta_3 = \theta \approx 15°$. It is easily understood that this corresponds in fact to an octet breaking of the colored $SU(3)$. Right-helicity currents in the model (2) "operate" in the color sector (along the horizontals of the matrix q). We assume for simplicity that $\theta' = 0$. The presence in the model (2) of weak currents of both helicities makes the theory free of triangle anomalies.[6]

Let us discuss the dynamic properties of the model (2). The charged quark current in the model is of the form

$$J_\mu^W = J_{\mu L}^3 + [\bar{n}_2 \gamma_\mu \lambda_3(\theta)]_L + [\bar{n}_1 \gamma_\mu n_3]_R + [\bar{\lambda}_2 \gamma_\mu \lambda_3]_R , \tag{3}$$

where $J_{\mu L}^3$ is the Cabibbo current for the "blue" p_3, n_3, and λ_3 quarks, and $(\bar{q}' \gamma_\mu q)_L = \bar{q}' \gamma_\mu (1 \pm \gamma_5) q$. It is easily seen that the matrix elements of the current J_μ^W between the ordinary hadrons are different from zero only for the first term. The remaining term can be of interest only for nonleptonic decays of white hadrons, or else for processes with participation of colored particles. The absence of a suppressing $\sin\theta$ factor in the right-helicity current $J_{\mu R}^W$ leads to several important consequences. First, as can be easily seen, the ($\Delta T = 1/2$) part

$$\mathcal{H}_w(1/2) \approx \frac{G}{\sqrt{2}} \cos\theta [\bar{n}_2 \gamma_\mu \lambda_3]_L [\bar{\lambda}_3 \gamma_\mu \lambda_2]_R \tag{4}$$

of the effective weak Hamiltonian is enhanced in comparison with its ($T = 3/2$) part from the current $J_{\mu L}^3$ by a factor $1/\sin\theta$. The Hamiltonian (4) gives the $(\bar{n}_2 \lambda_2)$ term in quark mass matrix, a term proportional, owing to the interaction of the L and R currents, to the mass of the λ_3 quark. Thus, the nonleptonic decays of the kaons and hyperons will now dominate over their leptonic modes, both as a consequence of the absence of kinematic suppression, and as a result of the large mass of m_{λ_3}. The interaction (4) makes also the main contribution to the difference between the masses of the K_L and K_S mesons. We plan to present a detailed discussion of this question elsewhere. We note, in addition, that the Hamiltonian (4) satisfies the Golovich-Holstein criterion,[7] meaning that the total quark current J_μ^W does not change the experimentally confirmed predictions of the current algebra for the characteristic hadronic decays of K mesons and hyperons.

Neutrino production of colored hadrons in the model (2) has a number of distinguishing features. Thus, quasielastic production of colored baryons "proceeds" freely both in a neutrino beam (current $[\bar{n}_3\gamma_\mu n_1]_R$) and in an antineutrino beam (currents $[n_2\gamma_\mu\lambda_3]_L$, $[\bar{n}_1\gamma_\mu n_3]_R$). On the other hand, the production of strange particles (as a result of the production and decay of colored hadrons), on account of the interaction with "valent" quarks of the target nucleons, takes place only in a $\bar{\nu}$ beam with a ratio $K/\pi \approx 1$ at large x. At small x, the ratio is $K/\pi \approx 1/2$ in both $\bar{\nu}$ and ν beams. Leptonic decays of colored hadrons give rise to $(\mu^+\mu^-)$ modes in ν and $\bar{\nu}$ production.[4] The model predicts here $\sigma^{\bar{\nu}}_{\mu\mu}/\sigma^{\nu}_{\mu\mu} \approx 1$ for small x and $\sigma^{\bar{\nu}}_{\mu\mu}/\sigma^{\nu}_{\mu\mu} \approx 2$ for large ones. On the other hand the appearance of dimuons with the same sign of the charge should be regarded as the result of associative production of a pair of colored hadrons with subsequent decay of one of them into leptons.

We shall group the leptons, in analogy with the quarks, into "left" and "right" doublets:

$$\begin{pmatrix} \nu_e & \nu_\mu \\ E^-(a) & M^-(a) \end{pmatrix}_L , \quad \begin{pmatrix} E^\circ & M^\circ \\ E^- & M^- \end{pmatrix}_R , \tag{5}$$

where

$$E_L^-(a) = \frac{\sqrt{8}}{3} E_L^- + \frac{1}{3} e_L^- , \quad M_L^-(a) = \frac{\sqrt{8}}{3} M_L^- + \frac{1}{3} \mu_L^- ; \; E^-, \; E^\circ, \; M^-,$$

are new heavy leptons of the electron and muon type, respectively. The mixing introduced in (5) is necessary to ensure universality of the weak interaction in μ and β decay, since the quark current (3) taken in operator brackets with the ordinary hadrons h' and h, is

$$< h' | J_\mu^W | h > = < h' | J^3_{\mu L} | h > = \frac{1}{3} \sum_i < h' | J^i_{\mu L} | h > = \frac{1}{3} < h' | J_\mu^C | h > , \tag{6}$$

where J_μ^C is the Cabibbo current, a "colored" singlet. It is easily seen that in this case the lower bound of the W-boson mass is decreased. The usual reasoning [6] yields $m_W > 12.4$ GeV. The mixing in (5), which we have introduced for the charged components alone or even for both components simultaneously. It is important, however, to emphasized that the existing data on neutral currents (see [5]), namely the high level of the neutral hadron current, exclude fully the second possibility, leaving only the first and the third. This makes it necessary to assume the existence of heavy charged leptons of both type, which can be of interest in connection with the observation of the "anomalous" (μe) events in (e^+e^-) annihilation processes.[8]

To guarantee for all the fermions—quarks and leptons—a realistic mass spectrum, it is necessary to introduce three scalar fields: to complex doublets ϕ and χ, and one real triplet $\vec{\phi}$, with vacuum expectation values

$$< \phi > = \begin{pmatrix} \lambda \\ 0 \end{pmatrix}, \quad < \chi > = \begin{pmatrix} 0 \\ \kappa \end{pmatrix}, \quad < \vec{\phi} > = \begin{matrix} 0 \\ \delta \\ 0 \end{matrix} .$$

The mass matrix of the leptons then takes the form

$$L_m = - M\bar{D}D - m\bar{S}^- S^- + h\bar{D}\vec{\tau} D \vec{\phi} + g_1 \bar{D} S_L^0 \phi + g_2 D S_L^- \chi + g_3 \bar{D} S_R^- \lambda + h.c., \tag{7}$$

where D is a doublet, electronic or muonic; $S_L^0 = E_L^0(M_L^0)$, and S^0 denotes singlets orthogonal to $E^0(\alpha)$ and $M^-(\alpha)$. Quark masses arise analogously.

We conclude our analysis by discussing the properties of the neutral current J_μ^Z in the model (2). The current J_μ^Z, taken between the nucleon bracket operators, "becomes discolored" and assumes a simple form (we shall not write out the bracket operators):

$$j_\mu^Z = \frac{1}{3}\left[\frac{1}{2}\bar{p}\gamma_\mu(1+\gamma_5)p + 2\sin^2\theta_W \bar{n}\gamma_\mu n\right], \tag{8}$$

where θ_W is the Weinberg angle[6] and the dots stand for terms connected with the λ quark. The corresponding effective Lagrangian is written in the form

$$L_{\nu_2} = \frac{3}{\sqrt{2}} G x \bar{\nu}\gamma_\mu(1+\gamma_5)\nu[v_S j_\mu^s + a_s j_{5\mu}^s + v_3 j_\mu^3 + a_3 j_{5\mu}^3], \tag{9}$$

where

$$G = \frac{g^2}{72 m_W^2}, \quad x = \frac{m_W^2}{m_Z^2 \cos^2\theta_W}, \quad m_W = \frac{12.4\ GeV}{\sin\theta_W},$$

the coefficients of the isoscalar and isovector combinations in the current J_μ^Z are

$$v_s = ½ + 2\sin^2\theta_W, \quad a_s = ½, \quad v_3 = ½ - 2\sin^2\theta_W, \quad a_3 = ½. \tag{10}$$

We turn now to the data on the neutral currents.[5] According to (3), (9), and (10), the ratios R_ν and

$$R_{\bar{\nu}}(R_\nu \equiv \sigma(\nu + N \to \nu + \ldots)/\sigma(\nu + N \to \mu + \ldots))$$

are equal to

$$R_\nu = 9x^2\left(\frac{1}{4} + \frac{4}{3}\sin^4\theta_W\right), \quad R_{\bar{\nu}} = 9x^2\left(\frac{1}{4} + 4\sin^4\theta_W\right). \tag{11}$$

Taking the experimental data of R in the form of the intervals $R_\nu = 0.19 - 0.25$ and $R_{\bar{\nu}} = 0.48 - 0.62$ we obtain $0 < x < 0.25$, $\sin^2\theta_W > 0.35$. The last limitation leads to the important conclusion that the current J_μ^Z has an isoscalar structure (for the mean values in the intervals R_ν and $R_{\bar{\nu}}$ we have $v_s \approx 2$, $v_3 \approx -1$), as is apparently indicated seriously by the latest measurements. It is also of interest to present the ensuing bounds on the masses of weak bosons: 21 GeV $> m_W > 12.4$ GeV and $m_Z > 50$ GeV.

The author is grateful to A. A. Ansel'm, A.D. Dologov, O. V. Kancheli, and V.M. Shekhter for discussions of a number of questions touched upon in the article.

[1]M. Y. Han and Y. Nambu, Phys. Rev. 139B, 1038 (1965).
[2]A. N. Tavkhelidze, Proc. Sem. on High-Energy Physics and Elementary Particles, Vienna, 1965.
[3]J. E. Augstin *et al*. Phys. Rev. Lett. **34**, 764 (1975).
[4]A. Benvenuti *et al*., Phys. Rev. Lett. **35**, 1199, 1203 (1975).
[5]J. J. Sakurai, Ref. TH. 2099-CERN, December 1975.
[6]S. Weinberg, Rev. Mod. Phys. **46**, 255 (1975).
[7]E. Glowich and R. Holstein, Phys. Rev. Lett. **35**, 831 (1975).
[8]M. Perl *et al*., Phys. Rev. Lett. **35**, 1489 (1975).