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NOTE ON SEARCHES FOR INTERMEDIATE BOSONS

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Experimental searches for intermediate bosons of weak interactions are being planned for all the new high-energy accelerators. The main method for their observation is assumed to be detection of their decay, which correspond to the presently well-known leptonic and hadronic weak reactions in the current - virtual boson - current scheme. In view of the particular importance of the problem, it pays to call attention to the fact that the character of this correspondence between the picture of the decays of real intermediate bosons and the known weak interactions may be appreciably altered if one uses not the generally accepted theory of universal interaction but a "multicurrent" theory of weak interactions of the Gell-Mann - Goldberger - Kroll - Low type [1]. It will be shown here that in this case there appears a unique possibility of an appreciable difference between the intensities of the "diagonal" and "nondiagonal" reactions of the current - real boson - current type. This difference is analogous to the previously indicated [1] difference for current-current reactions with virtual intermediate bosons. In conclusion, another alternative possibility is also indicated.

We consider the simplest multicurrent model of weak interactions of charged currents in the first approximation of perturbation theory, starting from a Lagrangian of the type

$$L = g\sum_{k=0}^{N} J_k X_k + \text{h.c.} \qquad J_k \equiv \sum_{i=1}^{N+1} \epsilon_i^k j_i \, , \tag{1}$$

$$\epsilon_i^0 = 1, \qquad i = 1, 2, \dots (N+1), \tag{2}$$

where the 4-vector indices of the currents and the fields have been omitted; g and ϵ_i^k are real parameters, and j_i are different leptonic and hadronic current elements (both the well-known (V - A) elements of the type $e\gamma_\alpha(1 + \gamma_5)\nu_e$ etc., and possibly some that are still unknown, see below), and (N + 1) is their total number. Here X_k are local operators of intermediate boson fields, which, following [1], we shall assume to be certain superpositions of vector and scalar fields. Unlike [1], in the zeroth approximation in the interaction (1), the mass matrix of the intermediate bosons is assumed here to be diagonal. We stipulate that in the approximation where all the masses of the intermediate bosons are equal, the nondiagonal interactions of the current j_i

vanish, and their diagonal interactions have a symmetry with a concrete form which should preferably not be limited. This requirement leads directly to the relation

$$1 + \sum_{k=1}^{N} \epsilon_i^k \, {}_j^k = \gamma_i \delta_{ij} . \tag{3}$$

In order for (3) and (2) to be compatible it is necessary to satisfy the condition

$$\sum_{i=1}^{N+1} 1/\gamma_i = 1 , \tag{4}$$

where γ_i are the coefficients of the squares of the currents in the expression $\sum_i \gamma_i j_i^+ j_i$. The simplest choice of the operators X_k with two bare-mass parameters

$$(X_o)_\alpha = (V_o)_\alpha + \frac{1}{M_1} \frac{\partial \phi_o}{\partial x_\alpha} , \quad (X_k)_\alpha = (V_k)_\alpha + \frac{1}{M_o} \frac{\partial \phi_k}{\partial x_\alpha} , \tag{5}$$

where the 4-vector indices α are explicitly written out, $(V_0)_\alpha$ and ϕ_k, $k \neq 0$, are the vector and scalar fields with equal masses M_0, and $(V_k)_\alpha$ and ϕ_0 have masses $M_k = M_1 > M_0$, now leads to the following effective current-current interaction

$$\mathcal{Z} = g^2 \sum_{i,k=1}^{N+1} j_i^+ j_k \Delta_{ik} \tag{6}$$

with a universal regularized effective nondiagonal propagator of the form

$$\Delta_{ik}^{\alpha\beta} = \left(\frac{1}{q^2 + M_o^2} - \frac{1}{q^2 + M_1^2} \right) \delta_{\alpha\beta} , \quad i \neq k , \tag{7}$$

and with an effective diagonal propagator

$$\Delta_{ii}^{\alpha\beta} = \left(\frac{1}{q^2 + M_o^2} + \frac{\gamma_i - 1}{q^2 + M_1^2} \right) \delta_{\alpha\beta} + \gamma_i \, q_\alpha q_\beta \times$$

$$\times \left[\frac{1}{M_o^2 (q^2 + M_o^2)} + \frac{1}{M_1^2 (q^2 + M_1^2)} \right] , \tag{8}$$

where q_α is the 4-momentum transfer. We note that the ϵ_i^k have been eliminated from (7) and (8). In the case when the γ_i do not depend on i, we get from (4) $\gamma_i = (N + 1)$ and the propagator (8), and consequently also the diagonal interactions, are also universal[1]. It follows from (7) and (8) that at $M_1 \approx M_0$ the diagonal interactions greatly exceed the nondiagonal ones in strength even in the lowest approximation.

Very little is known at present concerning the diagonal interactions. According to [3], the parity-nonconserving nuclear forces [4] should be classified more readily as "nondiagonal," and the parity conserving hadronic diagonal interactions do not differ in symmetry from the strong ones. The available data [5 - 7] on leptonic diagonal νe scattering do not exclude some difference between G_{diag} and G_F. What is most important for the following, however, is that at not too large momentum transfers, $E^2_{cm} \ll M^2$, the amplitude of the reaction $\nu_e e \to \nu_e e$ can generally vanish in the first approximation, if there exists a neutral current in the form

$$J_e^{(o)} \equiv (\bar{\nu}_e O_\alpha \nu_e - \bar{e} O_\alpha e), \quad O_\alpha = (1 \pm \gamma_5)\gamma_\alpha , \tag{9}$$

which interacts with itself with an effective low-energy constant $G_{diag} = G_F/2$. Such a possibility was first discussed in detail by B. Pontecorvo [8][2]. Obviously, even if the indicated "masking" of the leptonic diagonal interactions is actually realized in nature, it still cannot concern the reactions with strong intermediate bosons, since the neutral intermediate W^0 bosons do not interact with the Coulomb field. Under what conditions is the character of the difference between the diagonal and nondiagonal current-current weak interactions conserved also for reactions proceeding with production of short-lived real intermediate bosons?

Let us consider first the case when all the bare masses are equal, $M_1 = M_0$. The interaction (1) can then be rewritten in the form

$$L = g \sum_{i=1}^{N+1} j_i \tilde{X}_i + \text{h.c.}, \tag{10}$$

where

$$\tilde{X}_i = \sum_{k=0}^{N} \epsilon_i^k X_k . \tag{11}$$

In the zeroth approximation in the interaction (1), both the X_k and the $\tilde{X}_k$ bosons have definite masses that are equal to each other. When the interaction (1) is "turned on," the X_k fields no longer have definite masses, but the $\tilde{X}_k$ fields do not go over into one another, as before, and only acquire small

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[1] The multicurrent theory scheme proposed here has, in our opinion, the methodological advantage that it can also be used directly to describe a system of coupled interactions of neutral currents, which essentially includes the electromagnetic interactions. It is a generalization of the scheme of [2], where a particular case is considered with (N + 1) = 4, $\gamma_i = 4$, $M_0 = 0$, and X_0 is a photon and $J_0 \equiv J^{em}$ is the total electromagnetic current.

[2] We note that, in contrast to Bludman's scheme [9], there is no complete cancellation in the scheme of leptonic isotopic symmetry with two neutrinos, ν_e and ν_μ [10], provided one does not introduce different masses for the charged and neutral intermediate bosons.

complex increments to the bare masses (displacement of the masses and widths appear). If we denote by $T_{ki}(E)$ the total amplitude for the production and decay of real intermediate bosons, which relates the input channel i (current j_i) with the output channel k (current j_k), then in this case it is equal to zero, by virtue of (10), at $i \neq k$. One can expect that at a sufficiently small difference between the bare masses

$$\Delta M \equiv (M_1 - M_0) \ll \Gamma, \tag{12}$$

where Γ is the characteristic width of the intermediate bosons, the cross sections of the nondiagonal reactions will be small with the cross sections of the diagonal reactions in accordance with the rough estimate

$$|T_{ki}(E)/T_{ii}(E)| \approx \Delta M/\Gamma, \quad i \neq k, \tag{13}$$

as a consequence of the interference of the overlapping levels[3]. Then the effective intermediate boson will "remember" how it was produced: the W bosons produced in hadronic reactions will decay predominantly into hadrons, while the leptonic decays will be suppressed; if the $(\nu_\mu \mu)$ and $(\nu_e e)$ currents are "different" currents, then the W bosons produced by the muonic neutrino will decay predominantly into muons, and the decays into electrons and hadrons will be suppressed, etc.

Let us obtain some estimates for the attractive particular case of a model with $g = \sqrt{4\pi}e$, where $e^2 = 1/137$. We emphasize here that, unlike the single-current theory, in the present model the conditions $g = e$ and $M_W \ll 100$ GeV are perfectly compatible. Equating the effective low-energy 4-fermion coupling constant that follows from (7) to the Fermi constant G_F, we get[4]

$$\Delta M \approx \frac{G_F M_0^3}{8\pi\sqrt{2}e^2} \approx \frac{1}{22}\left(\frac{M_0}{10}\right)^3 \text{(GeV)}. \tag{14}$$

On the other hand, for example for the vector boson, the width of the leptonic decay is

$$\Gamma_\ell = w(w \to \ell + \nu_\ell) \approx \frac{2}{3} e^2 M_w \approx M_0/200 . \tag{15}$$

Choosing $M_W = 8$ GeV, we obtain, for example

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[3] Here E is the energy of the boson decay products in the c.m.s. General formula for the amplitude $T_{ki}(E)$ in the energy representation are given and discussed in the paper of Kobzarev, Nikolaev, and Okun' [11]. Using these formulas, and also the explicit expression for the CP-invariant interaction (1) and relation (3), we can easily verify by direct calculation that under the condition (12) the mean values of the n-th degrees of the non-Hermitian mass H-matrix of the X bosons of second order of the type $(A^{(k)}, H^n, M^{(i)})$, n = 1, 2, 3, ..., in the notation of [11], are proportional to ΔM when $i \neq k$, and this leads to relation (13).

[4] It is possible that the requirement that the universality of the nondiagonal interactions be retained when account is taken of the higher approximations in the diagonal interactions leads to a limitation on the possible symmetry of the latter (in particular, on the values of the parameters γ_i), and a relation of the type (14) can apparently be retained.

$$(M_1 - M_0) = 23\ \text{MeV},\quad \Gamma > \Gamma_\ell = 40\ \text{MeV}.$$

Thus, the proposed multicurrent model of weak interactions, including neutral currents, is of physical interest.

In conclusion, we note briefly still another alternate possibility, also peculiar to the multicurrent theory, which may turn out to be of interest in connection with searches for intermediate bosons. It is easy to verify that with increasing number of the parameters of the bare masses of the intermediate bosons it is possible, at will, to violate the universality of the nondiagonal interactions, by greatly suppressing some single "violating" group compared with others. If at the same time the levels of the masses of the intermediate bosons do not overlap, then, in view of the absence of interference phenomena, this suppression will generally not take place in decays of real intermediate bosons. Then, one cannot exclude in these decays considerable violations of the known weak-interaction selection rules, the conservation laws of certain charges, etc. One cannot exclude, for example, the possibility that channels of W-boson decays with single strange particles, with violation of the conservation of the lepton charge, of the rule $\Delta S = \Delta Q$, or others, will turn out to be not suppressed. In spite of the apparent artificiality of the latter possibilities, they should not be rejected a priori, since suprises can be expected at the threshold of W-boson production.

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In the article by E. M. Lipmanov, Vol. 14, No. 9, p. 365, formula (3) should read

$$1+\sum_{k=1}^{N} \epsilon_i^k \epsilon_j^k = \gamma_i \delta_{ij} .$$

In the same article, p. 366, line 9 from the top should begin with "between $G_{diag}^{(e\nu)}$ and G_F" instead of "between G_{diag} and G_F." On the same page, in the first line after Eq. (9), read "...$G_{diag}^{0} = G_{diag}^{(e\nu)}/2$" instead of "...$G_{diag} = G_F/2$."