the type of coupling obtained in reference 4 for the pion-nucleon interactions. In our point of view, however, the Yukawa-type pion-nucleon interactions are symmetry-violating interactions of SU(6). If we assume that the Yukawa interaction transforms as the 35 representation [simplest SU(6)-violating interaction], we have two independent couplings so that we do not necessarily have a definite type of coupling for the pion-nucleon interactions.

[10]Since we are not convinced of the relativistic extension of the group SU(6), contrary to the statement in reference 2, we apply this group in the static limit by assuming that it is an approximate symmetry valid only in this limit. We thank Professor L. Michel for his informative discussion on the extension of the Poincaré group.

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ISOTOPIC STRUCTURE OF THE WEAK INTERACTIONS*

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Recently,[1] striking evidence for the process

$$K_2^0 \to \pi^+ + \pi^- \tag{1}$$

has been reported, with a branching ratio of about 2×10^{-3} to all the other decay modes of K_2^0. Since this process is forbidden by CP invariance, its existence means that CP invariance is violated in the weak interactions. In the light of the CPT theorem, T invariance, too, is violated. This development adds new fog to an already confused situation. So far, tentative partial explanations of the experimental facts have been made possible by assuming empirical nonconservation regularities, namely $\Delta I = \frac{1}{2}$ and $\Delta S = \Delta Q$ rules,[2,3] and, with the help of the spurion[4] trick, by pushing into the weak interactions, which are I- and S-nonconserving, the isotopic technique,[5] built into the strong ones on the assumption of I conservation. Even so, it is difficult to understand, from one side, the regularity in the violations, more than the violations in themselves. From another side there is much discussion yet about the validity of such rules and about the extent of their violation ($\Delta I = \frac{3}{2}$, $\Delta S = -\Delta Q$).[6-9] We are almost led to talk in terms, so to speak, of "regularities in the violation of the regularities of the violated conservation of isotopic spin." Still, the regularities in the weak interactions really exist, suggesting the existence of some underlying symmetry related to an isospinlike conservation. This idea is not new and several attempts in this sense are known,[10-16] but so far they have been limited mostly to the leptons. Summarizing, the trend has been to look at the weak interactions through the strong-interaction scheme, with its well conserved I and I_3, and to realize that they are no longer conserved: a curious, special way of being nonconserved, however.

The recent discovery of CP nonconservation, furthermore, robs the $\Delta I = \frac{1}{2}$ rule of most of its power. In fact, CP conservation together with the Pauli principle allowed in many cases the selection of one value for I out of the two consistent with $\Delta I = \frac{1}{2}$, thus allowing Clebsch-Gordan-type calculations to predict several ratios. If CP is not conserved, this is no longer possible: Two independent isotopic amplitudes are involved (for instance in K_2^0 decay), and even a more or less ad hoc statement about the "extent" of CP violation cannot give definite predictions without further assumptions on the relative "strength" of the two amplitudes.

It is the purpose of this note to suggest a way of reversing the trend by looking directly at the weak interactions to see if the present rules can be unified and understood on a more general basis. Namely, we propose to interpret the regularities shown by the weak interactions as due to the existence and to the conservation of a weak isotopic spin I' and of its third component I_3', related to the electric charge by

$$Q = \tfrac{1}{2}Y' + I_3', \tag{2}$$

which is the weak equivalent of the well-known

$$Q = \tfrac{1}{2}Y + I_3, \tag{2}$$

and where Y', the leptonic charge, is the weak equivalent of the hypercharge. Conservation of lepton number L and baryon number B as well as charge Q is, of course, also assumed. Our assignment for the proposed quantum numbers is shown in Table I. It may be observed that, for the hadrons, the weak-isotopic and the strong-isotopic grouping are the same for the nonhypercharged multiplets ($\pi\eta$, $\Sigma\Lambda$), while they differ for the hypercharged ones ($K\bar{K}$, $N\Xi$). The symmetry between mesons and baryons is complete; like the neutral kaons, B_1^0 and B_2^0 are constructed as superpositions of the strong correspondents n and Ξ^0.

As a first step, let us see how this model fits the experimental picture and to what extent it is able to incorporate the usual rules.

For the leptons, the nontrivial currents[25] are

$$\mu^+\bar{\nu}_\mu, e^+\nu_e; \quad I'=1,\ I_3'=+1;$$

$$\mu^-\nu_\mu, e^-\bar{\nu}_e; \quad I'=1,\ I_3'=-1. \tag{3}$$

The choice of μ^+ as a particle (instead of μ^-) is a matter of definition and leads only to a trivial redefinition of ν_μ and $\bar{\nu}_\mu$ in terms of their helicity. The only possible first-order interactions are therefore

$$\mu^+ \to e^+ + \nu_e + \nu_\mu,$$

$$\mu^- \to e^- + \bar{\nu}_e + \bar{\nu}_\mu. \tag{4}$$

Processes like

$$\mu^\pm \to e^\pm + e^+ + e^-,$$

$$\mu^\pm \to e^\pm + \gamma, \tag{5}$$

are forbidden.

Let us look at the mesons. The usual decay mode of the π follows at once from coupling it with the currents (3); π^0, having $I_3'=0$, can decay only via electromagnetic interactions; the same happens to the η singlet. As for the kaons, the K_1^0 singlet is, as of now, uncorrelated to the triplet. The 2π decay, being in s wave, must be in an even I' state ($I'=0, 2$). Then K_1^0 is allowed by I' conservation to decay into two pions, which will therefore be its dominant mode, while this decay is not allowed for the K_2^0. A simple Clebsch-Gordan

Table I. Proposed quantum numbers for the leptons and the meson and baryon octet.

		Q	B	L	Y'	I', I_3'
Leptons	μ^+	1	0	1	1	$\frac{1}{2}, \frac{1}{2}$
	ν_μ	0			1	$-\frac{1}{2}$
	ν_e	0			-1	$\frac{1}{2}, \frac{1}{2}$
	e^-	-1			-1	$-\frac{1}{2}$
$\lvert Y\rvert = 0$ meson	η	0	0	0	0	0, 0
	π^+	1				1
	π^0	0				1, 0
	π^-	-1				-1
$\lvert Y\rvert = 1$ meson	$K_1^0 = 2^{-1/2}(K^0 + \bar{K}^0)$	0	0	0	0	0, 0
	K^+	1				1
	$K_2^0 = 2^{-1/2}(K^0 - \bar{K}^0)$	0				1, 0
	K^-	-1				-1
$\lvert Y\rvert = 0$ baryon	Λ	0	1	0	0	0, 0
	Σ^+	1				1
	Σ^0	0				1, 0
	Σ^-	-1				-1
$\lvert Y\rvert = 1$ baryon	$B_1^0 = 2^{-1/2}(n + \Xi^0)$	0	1	0	0	0, 0
	p	1				1
	$B_2^0 = 2^{-1/2}(n - \Xi^0)$	0				1, 0
	Ξ^-	-1				-1

calculation yields the ratio

$$\frac{\Gamma(K_1^0 \to \pi^+ + \pi^-)}{\Gamma(K_1^0 \to \pi^0 + \pi^0)} = 2, \tag{6}$$

i.e., the neutral mode is 33.3 % of the total. One of the most recent results[17] gives the value (33.5 ± 1.4) %.

As for the K_2^0, if the 2π decay were directly allowed, one would expect it to be the dominant mode by a factor of ≤100. But it is I' forbidden and can take place only via electromagnetic breaking. This brings in a factor $\alpha^2 \sim 5\times10^{-5}$ and slows down the ratio to

$$\frac{\Gamma(K_2^0 \to \pi^+ + \pi^-)}{\Gamma(K_2^0 \to \text{other modes})} \leq 5\times10^{-3}, \tag{7}$$

in agreement with the ratio recently obtained.[1]

For the remaining nonleptonic decays, the results[18] of I' conservation alone are the same as those of the $\Delta I = \frac{1}{2}$ rule combined with CP invariance and are thus in accord with the experiments.[19-22]

For the leptonic decays, coupling the hadronic with the leptonic currents we find the following (charge symmetry is assumed):

$$\Gamma(K^+ \to \pi^0 + l^+ + \nu) : \Gamma(K_2^0 \to \pi^+ + l^- + \nu) : \Gamma(K_2^0 \to \pi^- + l^+ + \nu) = 1:1:1,$$

$$\Gamma(K_1^0 \to \pi^+ + l^- + \nu) : \Gamma(K_1^0 \to \pi^- + l^+ + \nu) = 1:1. \tag{8}$$

To predict the ratio of K_1^0/K_2^0 leptonic decay we must further specify the dynamics and the coupling of the two particles, which are in principle uncorrelated, as already mentioned. We will not go into details here; however, we would like to point out that while the $\Delta S=\Delta Q$ prediction (ratio = 1) is in a rather poor agreement with the experiments[6,23,24] (the possibility of some violation is in general admitted), even if the experiments, so far, are still not decisive, it seems that at least the agreement is easier with our model. For instance, just making the simplest assumption that the two matrix elements have the same value, we find

$$\frac{\Gamma(K_1^0\to\pi+l+\nu)}{\Gamma(K_2^0\to\pi+l+\nu)}=2. \qquad (9)$$

For the baryons, again the selection rule agrees completely with the experimental panorama, except for the $\Xi\to N$ decays which at this stage are allowed and can be forbidden by the additional rule

$$\Delta Y<2. \qquad (10)$$

To make numerical predictions, after finding a ratio involving B_1^0 or B_2^0, we have to go back to the neutron and the neutral cascade with the help of

$$n=2^{-1/2}(B_1^0+B_2^0),$$
$$\Xi^0=2^{-1/2}(B_1^0-B_2^0). \qquad (11)$$

Looking first at the nonleptonic decays, which are always the dominant ones and whose rates are quite well established (except for the Ξ^0), we find again the same results as the $\Delta I=\frac{1}{2}$ rule, in agreement with the present experimental data.[8] More detailed predictions can be made by specifying the matrix elements involved, but this is beyond the scope of the present discussion.

For the leptonic decays, all the known processes are allowed. Significant predictions are

$$\frac{\Gamma(\Sigma^+\to n+l^++\nu)}{\Gamma(\Sigma^-\to n+l^-+\nu)}=1, \qquad (12)$$

$$\frac{\Gamma(\Sigma^+\to\Lambda+l^++\nu)}{\Gamma(\Sigma^-\to\Lambda+l^-+\nu)}=1. \qquad (13)$$

So far it seems that the main features of the weak interactions can be understood in terms of the simple model proposed. The main advantage over the usual rules is treating on the same ground all the processes—lepton-lepton, nonleptonic, leptonic strangeness-changing, and strangeness-nonchanging decays—instead of asking for local nonconservation regularities. The isotopic technique, so far considered as a useful trick, now has a better foundation, and the results of the $\Delta I=\frac{1}{2}$ rule are easily explained: In fact, $\frac{1}{2}$ is just the difference between I and I' either for the decaying particle or for the decay products. It is not surprising, therefore that in general our model leads to results in accordance with those predicted by the $\Delta I=\frac{1}{2}$ rule. Its advantage, however, lies in the fact that its predictions do not depend on CP invariance, while those of the $\Delta I=\frac{1}{2}$ rule do. Furthermore, it leads to some noticeable improvements. For instance, the ratio (9) seems in better agreement with the experiment than that predicted by the $\Delta S=\Delta Q$ rule; the appearance of $K_2^0\to 2\pi$ is predicted with the right order of magnitude; the forbidden Σ^+ leptonic decay is now allowed in agreement with the increasing evidence in favor of its existence.[6] The fact that our scheme, while allowing this last process, gives a rate higher than that presently suggested by the experiment, could perhaps be related to the extreme difficulty in the identification of the process and with the very low statistics so far available. Higher statistics would be desirable to shed more light on this point. If strong evidence against the existence of the Σ^+ leptonic decay were reached, the rule $\Delta S=\Delta Q$ could be added, as an independent constraint, at this stage of our model.

Furthermore, we would like to point out that perhaps the choice of the values for I' and I_3', even if it is the most straightforward one, is not unique. We are left with a certain freedom, and the possibility that some other choice fits the experiments equally well or even better cannot be ruled out. The present choice, anyway, shows no contradiction with presently known experimental facts. It can be shown that I' can be conserved in the strong interactions (I_3', clearly, always is) without affecting any isotopic ratio.

It will be of great interest, now, to check if the model can be derived from a higher symmetry. If this should be the case it could provide a better foundation for the model itself and also detailed predictions about the relationship between presently independent matrix elements.

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