V. CONCLUSIONS

In Table II we summarize the recent measurements of ξ in K^+ lepton decays based on the hypothesis of real, constant form factors and vector coupling.

TABLE II. Summary of recent determinations of ξ.

	Method	ξ value
Our preliminary result[a]	Branching ratio	$+0.3\pm0.8$ (or -7.1 ± 0.8)
	Spectrum	>-3
This experiment	Branching ratio	$+0.6\pm0.5$ (or -7.3 ± 0.5)
	Spectrum (for χ^2 probability $>5\%$)	>-3.3
Gidal *et al.*[b]	Polarization	-0.15 ± 0.90 (or -4.05 ± 0.75)
Jensen *et al.*[c]	Branching ratio	-0.2 ± 0.8 (or -6.5 ± 0.8)
	Spectra and angular correlation	$+0.6\pm2.0$
	Combined result	-0.08 ± 0.7
Brown *et al.*[d]	Combined result	$+1.8\pm0.6$
Boyarski *et al.*[e]	Spectrum	-7.6
	Polarization	>-4
Giacomelli *et al.*[f]	Spectrum up to 25 MeV and branching ratio	$+0.7\pm0.5$

[a] See Ref. 5.
[b] G. Gidal, W. M. Powell, R. March, and S. Natali, Phys. Rev. Letters **13**, 95 (1964).
[c] G. L. Jensen, F. S. Shaklee, B. P. Roe, and D. Sinclair, Phys. Rev. **136**, B1431 (1964).
[d] J. L. Brown, J. A. Kadyk, G. H. Trilling, R. T. Van de Walle, B. P. Roe, and D. Sinclair, Phys. Rev. Letters **7**, 423 (1961); **8**, 450 (1962).
[e] A. M. Boyarski, E. C. Loch, L. Q. Niemela, D. M. Ritson, R. Weinstein and S. Ozaki, Phys. Rev. **128**, 2398 (1962).
[f] G. Giacomelli, D. Monti, G. Quareni, A. Quareni-Vignedelli, W. Püschel, and J. Tietge, Nuovo Cimento **34**, 1134 (1964).

The results of our analysis for real, constant form factors, in agreement with most of the previous results, indicate clearly a ξ value very near to zero. The high positive ξ values allowed by the spectrum shape are excluded by the branching-ratio value, while the spectrum shape excludes the high negative value compatible with the branching ratio.

For the imaginary part of ξ, no published results are available up to now. Our data are not selective enough to draw any conclusion about *CP* or *T* violation.

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Quartet Scheme and Weak Interactions*

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A unified scheme of weak interactions has been given within the framework of $SU(4)$ by means of intermediate bosons. We assume that the fundamental entities—leptons, intermediate bosons, and quarks—are all quartets. The damping of the $|\Delta S|=1$ transitions has been introduced either through the breakdown of the strong-interaction symmetry or through a certain mixing of unphysical neutrinos. The present theory possesses a complete symmetry between leptons and hadrons and accounts for (i) the $|\Delta I|=\frac{1}{2}$ rule and (ii) the weak-interaction Hamiltonian transforming like the sixth component of the unitary octet for the $|\Delta S|=1$ part of the nonleptonic (noncharmed) decays. The problem of the absence of neutral lepton currents remains.

I. INTRODUCTION

THE group $SU(4)$ has been introduced recently as a possible basis for the eightfold way which avoids the puzzle of nonintegral charges.[1,2] It has also been proposed as a symmetry for strong interactions.[3–6] So far, the latter proposal does not seem to be successful, but it suggests a possible "hadron-lepton symmetry.[1,2,5,6]" It could be that the $SU(4)$ symmetry is so badly broken that only the noncharmed parts[5] (i.e., the parts with charm number zero) of its $SU(3)$ subgroups correspond to the actual dominant symmetry of the strongly interacting particles (hadrons); and therefore the $SU(4)$ group will not be a reasonable scheme for strong interactions. On the other hand, since there are four distinct kinds of leptons and the minimum number of "the elementary hadrons" will be four if the charges of the quarks[1] are nonfractional, it is quite plausible that the $SU(4)$ symmetry will give a unified scheme for weak interactions.

* Work supported by the U. S. Atomic Energy Commission.
[1] M. Gell-Mann, Phys. Letters **8**, 214 (1964).
[2] Y. Hara, Phys. Rev. **134**, B701 (1964).
[3] P. Tarjanne and V. L. Teplitz, Phys. Rev. Letters **11**, 447 (1963).
[4] D. Amati, H. Bacry, J. Nuyts, and J. Prentki, Phys. Letters **11**, 190 (1964); Nuovo Cimento **34**, 1732 (1964).
[5] B. J. Bjorken and S. L. Glashow, Phys. Letters **11**, 255 (1964).
[6] Z. Maki and Y. Ohnuki, Progr. Theoret. Phys. (Kyoto) **32**, 144 (1964).

The theory of weak interactions based on the universal current-current interaction is quite successful and elegant. The theory can be summarized as follows[7–9]: The weak-interaction coupling is represented by a product of a weak current and its Hermitian conjugate: $(G/\sqrt{2})J_\alpha^\dagger J_\alpha$. The weak current J_α contains a leptonic part $j_\alpha^{(l)}$, which belongs to $SU(2)$, and a hadronic part $J_\alpha^{(h)}$, which belongs to the $SU(2)$ subgroup of $SU(3)$. There are two distinct views about the damping of the $|\Delta S|=1$ transitions.[8,10] One is that the suppression is due to the breakdown of the unitary symmetry.[11] The other view can be stated as follows: The weak hadron and lepton currents are of the same form in frame F' [12] and under the unitary transformation $U=\exp(-2i\theta F)$ we go to the physical frame F,[12] in which the hadron current then consists of a strangeness-conserving term and a strangeness-changing term of the Cabibbo form.[13] Next, we have to find a satisfactory explanation of the $|\Delta I|=\frac{1}{2}$ rule for the strangeness-changing part of the nonleptonic decays.[7,14–17] Moreover, the universal current-current interaction may be carried by the intermediate bosons.[17–19]

The purpose of this paper is to give a unified description of weak interactions on the basis of the $SU(4)$ symmetry by means of the intermediate bosons.[20] To this end, we shall assume that the fundamental entities—leptons, intermediate bosons, and quarks—are all quartets. Furthermore, we shall introduce a "lepton parity operator Λ" such that it is conserved for interactions involving leptons. On the basis of these assumptions, we can construct the weak lepton current and the lepton–intermediate-boson Lagrangian, and in turn, we can obtain the weak hadron current and the hadron–intermediate-boson Lagrangian in analogy to the leptonic case. The present scheme possesses a complete symmetry between the hadrons and the leptons. The suppression of the strangeness-changing transitions will be introduced either from the mixing of neutrinos or through the breakdown of the strong-interaction symmetry. We shall encounter the problem of the absence of neutral lepton currents.

[7] M. Gell-Mann, Physics **1**, 63 (1964).
[8] R. Oehme, Ann. Phys. (N.Y.) (to be published).
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[18] T. D. Lee and C. N. Yang, Phys. Rev. **119**, 1410 (1960).
[19] S. Okubo, Phys. Letters **8**, 362 (1964); C. Ryan, S. Okubo, and R. E. Marshak, Nuovo Cimento **34**, 753 (1964).
[20] The present scheme is related to the theory of d'Espagnat and Villachon in $SU(3)$. See Ref. (17).

II. FUNDAMENTAL ENTITIES AND CURRENTS

Since there exist four distinct kinds of leptons and more than three quarks[1] are needed if the charges of the quarks are of integral values, we shall postulate that all fundamental entities of leptons, intermediate bosons, and hadrons are quartets.

The lepton quartet is given by

$$l=\begin{pmatrix}\nu_1\\ e^-\\ \mu^-\\ \nu_2\end{pmatrix},\tag{1}$$

where ν_1 and ν_2 are four-component neutrinos from which the physical neutrionos ν_e and ν_μ can be obtained.[6] Regarding the intermediate boson quartet, we shall write it, for a reason we shall state later, as

$$W=\begin{pmatrix}W_{1/2}^{(+)}\\ W_{1/2}^{(0)}\\ W_0^{(0)}\\ W_0^{(+)}\end{pmatrix},\tag{2}$$

where the superscript denotes the charge and the subscript is the isospin index. We note that in the W quartet, the fourth intermediate boson $W_0^{(+)}$, instead of the triplet $(W_{1/2}^{(+)},W_{1/2}^{(0)},W_0^{(0)})$, has an additional quantum number.

On the other hand, the hadron quartet has the following quantum numbers[2,4,5]:

h	Y	I	I_3	χ	B
$d^{(0)}$	1	$\frac{1}{2}$	$\frac{1}{2}$	-1	1
$d^{(-)}$	1	$\frac{1}{2}$	$-\frac{1}{2}$	-1	1
$s^{(-)}$	0	0	0	-1	1
$b^{(0)}$	0	0	0	0	1

(3)

where B is the baryon number and χ is the charm number[5] which is conserved in the strong and electromagnetic interactions. The pseudoscalar mesons and the baryons can then be built up from the hadron quartet as follows[4–6]:

$$\begin{aligned}M_i{}^j&=\bar{h}_ih^j-\tfrac{1}{4}\delta_i{}^j\bar{h}_\lambda h^\lambda,\quad (i,j=1,2,3,4)\\ B_i{}^{jk}&=\tfrac{1}{2}\bar{h}_i(h^jh^k-h^kh^j)-\tfrac{1}{8}\delta_i{}^j\bar{h}_\lambda(h^\lambda h^k-h^kh^\lambda).\end{aligned}\tag{4}$$

However, we note that the $SU(4)$ symmetry for strong interactions could be so badly broken that only the noncharmed $SU(3)$ subgroups correspond to the actual physical symmetry.

The lepton current j_α and the hadron current J_α contain, in general, vector and axial-vector parts. Since they are conserved or partially conserved, the currents will be in the one- and 15-dimensional (regular) representations of $SU(14)$. Thus, they can be written as

$$\begin{aligned}j_{i\alpha}&=i\bar{l}\gamma_\alpha(1+\gamma_5)(\lambda_i/2)l,\\ J_{i\alpha}&=i\bar{h}\gamma_\alpha(1+\gamma_5)(\lambda_i/2)h,\end{aligned}\tag{5}$$

where $F_i=\lambda_i/2$ are the F spins in $SU(4)$,[4] which obey the following commutation rules:

$$[F_i,F_j]=if_{ijk}F_k\,,$$
$$[F_i,F_j{}^5]=if_{ijk}F_k{}^5\,, \qquad (6)$$
$$[F_i{}^5,F_j{}^5]=if_{ijk}F_k\,,\quad (i,j,k=1,\cdots 15)\,,$$

where f_{ijk} are the structure constants[21] of the group $SU(4)$. We note that not all components of currents will be responsible for weak interactions.

III. FUNDAMENTAL WEAK-INTERACTION LAGRANGIAN

The fundamental weak-interaction Lagrangian L (i.e., the lepton and hadron-intermediate boson Lagrangians) can be written as

$$L=g(L^{(l)}+L^{(h)}+L^{(l)\dagger}+L^{(h)\dagger}) \qquad (7)$$

and

$$L^{(l)}=j^{(\dagger)}\cdot W\,,$$
$$L^{(h)}=J^{(\dagger)}\cdot W\,, \qquad (8)$$

where $L^{(l)}$ stands for the leptonic contribution and is in general a linear combination of products of the weak lepton currents $(j^{(\dagger)})_\beta{}^\alpha$ with the intermediate-boson fields W^γ, while $L^{(h)}$ stands for the hadronic contribution.

Since the lepton current j_α and the hadron current J_α are in the regular representations $\{1\}+\{15\}$ and the intermediate-boson field W is in the representation $\{4\}$, $L^{(l)}$, and $L^{(h)}$ will be in one of the following representations[3–5]:

$$\{4\}\quad\text{or}\quad\{\overline{20}\}\quad\text{or}\quad\{36\}\,. \qquad (9)$$

It is rather natural to ascribe $L^{(l)}$ and $L^{(h)}$ to the lowest representation $\{4\}$, because the other representations $\{\overline{20}\}$ and $\{36\}$ are too complicated and will not account for the nonleptonic $|\Delta I|=\frac{1}{2}$ rule. Equation (8) then becomes

$$(L^{(l)})^\alpha=(j^{(+)})_\beta{}^\alpha W^\beta\,,$$
$$(L^{(h)})^\alpha=(J^{(+)})_\beta{}^\alpha W^\beta\,,\quad(\alpha,\beta=1,2,3,4)\,. \qquad (10)$$

The over-all weak-interaction Hamiltonian H can then be written as

$$H=g^2(L^{(l)\dagger}L^{(l)}+L^{(l)\dagger}L^{(h)}+L^{(h)\dagger}L^{(l)}+L^{(h)\dagger}L^{(h)})\,. \qquad (11)$$

The first term $g^2L^{(l)\dagger}L^{(l)}$ in (11) contributes to the purely leptonic decays, and the second and third terms $g^2(L^{(l)\dagger}L^{(h)}+L^{(h)\dagger}L^{(l)})$ contribute to the semileptonic decays, while the last term $g^2L^{(h)\dagger}L^{(h)}$ is responsible for the nonleptonic decays. Here we shall assume that the charm number is violated in weak interactions.[2,5]

We see that the Hamiltonian $\mathcal{H}$ transforms with respect to $SU(4)$ like

$$\{4\}\times\{\bar{4}\}=\{1\}+\{15\}\,. \qquad (12)$$

If we consider only the noncharmed parts of the nonleptonic interaction $g^2L^{(h)\dagger}L^{(h)}$, it transforms with respect to $SU(3)$ like

$$\{3\}\times\{\bar{3}\}=\{1\}+\{8\}\,. \qquad (13)$$

This means that the Hamiltonian for the nonleptonic noncharmed reactions transforms like members of a unitary octet and hence it gives rise to the nonleptonic $|\Delta I|=\frac{1}{2}$ rule for the $|\Delta S|=1$ transitions.[17]

In the following sections we shall construct explicitly the weak currents and the weak interaction Lagrangians and investigate their consequences.

IV. SOME PROPERTIES OF LEPTONS

We shall introduce here a "lepton parity operator Λ" which is conserved in processes involving leptons. In the following, we shall consider two possible cases for the properties of the operator Λ corresponding to two possible ways of introducing the damping of the $|\Delta S|=1$ transitions:

Case I. The lepton parity operator Λ has the following properties:

$$\Lambda e^-=-e^-\,,\quad \Lambda\nu_e=-\nu_e\,,$$
$$\Lambda\mu^-=\mu^-\,,\quad \Lambda\nu_\mu=\nu_\mu\,, \qquad (14)$$

and

$$\Lambda\nu_1=\nu_2,\qquad \Lambda\nu_2=\nu_1\,.$$

Because "the lepton parity" is conserved, the physical neutrino ν_e (or ν_μ) associated with the electron (or the muon) should have the same Λ parity as that of the electron (or the muon). The last properties of Λ will lead us to express ν_e and ν_μ in terms of ν_1 and ν_2 as

$$\nu_e=\nu_1-\nu_2\,,$$
$$\nu_\mu=\nu_1+\nu_2\,. \qquad (15)$$

For antiparticles, we have

$$\Lambda e^+=-e^+\,,\quad \Lambda\bar{\nu}_e=-\bar{\nu}_e\,, \qquad (16)$$
$$\Lambda\mu^+=\mu^+\,,\quad \Lambda\bar{\nu}_\mu=\bar{\nu}_\mu\,,$$

and

$$\bar{\nu}_e=\bar{\nu}_1-\bar{\nu}_2\,,$$
$$\bar{\nu}_\mu=\bar{\nu}_1+\bar{\nu}_2\,. \qquad (17)$$

We see that the electron and the muon numbers are nothing but the lepton number with the opposite lepton parities, and that their separate conservations indicate just the conservations of the lepton number and parity. In the present case, the damping of the $|\Delta S|=1$ transitions will come from the breakdown of the strong-interaction symmetry,[8,11] and has nothing to do with the leptons.

Case II. In the present case the physical neutrinos ν_e and ν_μ, for some unknown reason, will be obtained from the unphysical neutrinos ν_1 and ν_2 as[6]

$$\nu_e=\nu_1\cos\theta-\nu_2\sin\theta\,,$$
$$\nu_\mu=\nu_1\sin\theta+\nu_2\cos\theta\,. \qquad (18)$$

[21] N. Dallaporta and T. Toyoda, Nuovo Cimento **35**, 586 (1965).

The lepton parity operator Λ has the following properties as in case I:

$$\Lambda e^- = -e^-, \quad \Lambda\nu_e = -\nu_e, \qquad \Lambda\mu^- = \mu^-, \quad \Lambda\nu_\mu = \nu_\mu. \tag{19}$$

Equations (18) and (19) give us some additional properties of Λ:

$$\Lambda\nu_1\cos\theta = \nu_2\sin\theta, \quad \Lambda\nu_1\sin\theta = \nu_2\cos\theta, \qquad \Lambda\nu_2\cos\theta = \nu_1\sin\theta, \quad \Lambda\nu_2\sin\theta = \nu_1\cos\theta. \tag{20}$$

For antiparticles, we have

$$\Lambda e^+ = -e^+, \quad \Lambda\bar{\nu}_e = -\bar{\nu}_e, \qquad \Lambda\mu^+ = \mu^+, \quad \Lambda\bar{\nu}_\mu = \bar{\nu}_\mu, \tag{21}$$

and

$$\bar{\nu}_e = \bar{\nu}_1\cos\theta - \bar{\nu}_2\sin\theta, \qquad \bar{\nu}_\mu = \bar{\nu}_1\sin\theta + \bar{\nu}_2\cos\theta, \tag{22}$$

where θ is the Cabibbo angle. In this case the origin of the suppression of the $|\Delta S|=1$ transitions is due to the peculiar mixing of neutrinos and has nothing to do with the hadrons.

V. THE WEAK LEPTON CURRENT AND LAGRANGIAN

Let us construct the weak lepton current and the lepton–intermediate-boson Lagrangian following the assumptions postulated before. Since the lepton currents $j_\beta{}^\alpha$ are in the representations $\{1\}+\{15\}$ and the lepton parity is conserved, we are able to write down the weak lepton currents and the lepton–intermediate-boson Lagrangian. [Hereafter we shall denote $\alpha = i\gamma_\alpha(1+\gamma_5)$.]

Case I. The weak lepton current, as allowed by the lepton parity, can be written as case I:

$$j_\beta{}^\alpha = \begin{pmatrix} (\bar{\nu}_1\alpha\nu_1) & (\bar{\nu}_1\alpha e^-) & (\bar{\nu}_1\alpha\mu^-) & (\bar{\nu}_1\alpha\nu_2) \\ (e^+\alpha\nu_1) & (e^+\alpha e^-) & 0 & (e^+\alpha\nu_2) \\ (\mu^+\alpha\nu_1) & 0 & (\mu^+\alpha\mu^-) & (\mu^+\alpha\nu_2) \\ (\bar{\nu}_2\alpha\nu_1) & (\bar{\nu}_2\alpha e^-) & (\bar{\nu}_2\alpha\mu^-) & (\bar{\nu}_2\alpha\nu_2) \end{pmatrix}. \tag{23}$$

The lepton–intermediate-boson Lagrangian is then (omitting g)

$$(L^{(l)})^\alpha = (j^{(\dagger)})_\beta{}^\alpha W^\beta = \begin{bmatrix} W_{1/2}{}^{(+)}(\bar{\nu}_1\alpha\nu_1) + W_{1/2}{}^{(0)}(e^+\alpha\nu_1) + W_0{}^{(0)}(\mu^+\alpha\nu_1) + W_0{}^{(+)}(\bar{\nu}_2\alpha\nu_1) \\ W_{1/2}{}^{(+)}(\bar{\nu}_1\alpha e^-) + W_{1/2}{}^{(0)}(e^+\alpha e^-) + W_0{}^{(+)}(\bar{\nu}_2\alpha e^-) \\ W_{1/2}{}^{(+)}(\bar{\nu}_1\alpha\mu^-) + W_0{}^{(0)}(\mu^+\alpha\mu^-) + W_0{}^{(+)}(\bar{\nu}_2\alpha\mu^-) \\ W_{1/2}{}^{(+)}(\bar{\nu}_1\alpha\nu_2) + W_{1/2}{}^{(0)}(e^+\alpha\nu_2) + W_0{}^{(0)}(\mu^+\alpha\nu_2) + W_0{}^{(+)}(\bar{\nu}_2\alpha\nu_2) \end{bmatrix}. \tag{24}$$

By our choice of the intermediate-boson quartet W, the charge is not conserved for the first and last rows in (24). We shall introduce here a spurion quartet S to project them out. In order to obtain a proper linear combination of ν_1 and ν_2 for the physical neutrinos ν_e and ν_μ, we shall define the spurion quartet S as

$$S = \begin{pmatrix} 0 \\ 1 \\ 1 \\ 0 \end{pmatrix} \text{ for noncharmed currents,} \qquad = \begin{pmatrix} 0 \\ -1 \\ 1 \\ 0 \end{pmatrix} \text{ for charmed currents.} \tag{25}$$

The effective lepton–intermediate-boson Lagrangian, which is the scalar product of $L^{(l)}$ and the spurion quartet S, is then a formal invariant in $SU(4)$:

$$\begin{aligned} L'^{(l)} &= (S^+)_\alpha (L^{(l)})^\alpha, \\ &= W_{1/2}{}^{(+)}(\bar{\nu}_1\alpha e^-) + W_{1/2}{}^{(0)}(e^+\alpha e^-) - W_0{}^{(+)}(\bar{\nu}_2\alpha e^-) \\ &\quad + W_{1/2}{}^{(+)}(\bar{\nu}_1\alpha\mu^-) + W_0{}^{(0)}(\mu^+\alpha\mu^-) + W_0{}^{(+)}(\bar{\nu}_2\alpha\mu^-). \end{aligned} \tag{26}$$

We shall assume that as the result of the $\nu_1-\nu_2$ mixing the intermediate boson $W_{1/2}{}^{(+)}$ (or $W_0{}^{(+)}$) will couple to $W_0{}^{(-)}$ (or $W_{1/2}{}^{(-)}$) with the same strength as the coupling to its antiparticle. Then we can write (26) as

$$\begin{aligned} L'^{(l)} = W^{(+)}(\bar{\nu}_e\alpha e^-) + W^{(+)}(\bar{\nu}_\mu\alpha\mu^-) \\ + W_{1/2}{}^{(0)}(e^+\alpha e^-) + W_0{}^{(0)}(\mu^+\alpha\mu^-). \end{aligned} \tag{27}$$

We note that because of our choice of the intermediate-boson quartet W the neutral currents $(\bar{\nu}_1\alpha\nu_1)$ and $(\bar{\nu}_2\alpha\nu_2)$ are absent.

Case II. In this case we shall introduce the Cabibbo angle through the spurion quartet as the result of the peculiar mixing of neutrinos as shown in Eq. (18). Hence the weak lepton currents $j_\beta{}^\alpha$ and the intermediate-boson–current interaction Lagrangian $L^{(l)}$ are the same as case I.

We shall define the spurion quartet S' in the present case as

$$S' = \begin{pmatrix} 0 \\ \cos\theta \\ \sin\theta \\ 0 \end{pmatrix} \text{ for noncharmed currents,} \qquad = \begin{pmatrix} 0 \\ -\sin\theta \\ \cos\theta \\ 0 \end{pmatrix} \text{ for charmed currents,} \tag{28}$$

where θ is the Cabibbo angle. The effective lepton–intermediate-boson Lagrangian is then

$$\begin{aligned}L'^{(l)}=&(S'^{+})_\alpha(L^{(l)})^\alpha\\ =&W_{1/2}^{(+)}(\bar\nu_1\alpha e^-)\cos\theta+W_{1/2}^{(0)}(e^+\alpha e^-)\cos\theta\\ &-W_0^{(+)}(\bar\nu_2\alpha e^-)\sin\theta+W^{(+)}(\bar\nu_1\alpha\mu^-)\sin\theta\\ &+W_0^{(0)}(\mu^+\alpha\mu^-)\sin\theta+W_0^{(+)}(\bar\nu_2\alpha\mu^-)\cos\theta.\end{aligned}\tag{29}$$

If we assume also that $W_{1/2}^{(+)}$ (or $W_0^{(+)}$) will couple to $W_0^{(-)}$ (or $W_{1/2}^{(-)}$) with the same strength as the coupling to its antiparticle, we have then

$$\begin{aligned}L'^{(l)}=&W^{(+)}(\bar\nu_e\alpha e^-)+W^{(+)}(\bar\nu_\mu\alpha\mu^-)\\ &+W_{1/2}^{(0)}(e^+\alpha e^-)\cos\theta+W_0^{(0)}(\mu^+\alpha\mu^-)\sin\theta.\end{aligned}\tag{30}$$

VI. THE WEAK HADRON CURRENT AND LAGRANGIAN

The weak hadron current and the hadron–intermediate-boson Lagrangian can be obtained in analogy to the leptonic case.

Case I. The hadron current can be written as

$$J_\beta{}^\alpha=\begin{bmatrix}(\bar d^{(0)}\alpha d^{(0)}), & (\bar d^{(0)}\alpha d^{(-)}), & (\bar d^{(0)}\alpha s^{(-)}), & (\bar d^{(0)}\alpha b^{(0)})\\ (d^{(+)}\alpha d^{(0)}), & (d^{(+)}\alpha d^{(-)}), & (d^{(+)}\alpha s^{(-)}), & (d^{(+)}\alpha b^{(0)})\\ (s^{(+)}\alpha d^{(0)}), & (s^{(+)}\alpha d^{(-)}), & (s^{(+)}\alpha s^{(-)}), & (s^{(+)}\alpha b^{(0)})\\ (\bar b^{(0)}\alpha d^{(0)}), & (\bar b^{(0)}\alpha d^{(-)}), & (\bar b^{(0)}\alpha s^{(-)}), & (\bar b^{(0)}\alpha b^{(0)})\end{bmatrix}.\tag{31}$$

All terms of the currents are allowed for hadrons. The hadron–intermediate-boson Lagrangian is then given by

$$(L^{(h)})^\alpha=(J^{(\dagger)})_\beta{}^\alpha W^\beta=\begin{bmatrix}W_{1/2}^{(+)}(\bar d^{(0)}\alpha d^{(0)})+W_{1/2}^{(0)}(d^{(+)}\alpha d^{(0)})+W_0^{(0)}(s^{(+)}\alpha d^{(0)})+W_0^{(+)}(\bar b^{(0)}\alpha d^{(0)})\\ W_{1/2}^{(+)}(\bar d^{(0)}\alpha d^{(-)})+W_{1/2}^{(0)}(d^{(+)}\alpha d^{(-)})+W^{(0)}(s^{(+)}\alpha d^{(-)})+W_0^{(+)}(\bar b^{(0)}\alpha d^{(-)})\\ W_{1/2}^{(+)}(\bar d^{(0)}\alpha s^{(-)})+W_{1/2}^{(0)}(d^{(+)}\alpha s^{(-)})+W_0^{(0)}(s^{(+)}\alpha s^{(-)})+W_0^{(+)}(\bar b^{(0)}\alpha s^{(-)})\\ W_{1/2}^{(+)}(\bar d^{(0)}\alpha b^{(0)})+W_{1/2}^{(0)}(d^{(+)}\alpha b^{(0)})+W_0^{(0)}(s^{(+)}\alpha b^{(0)})+W_0^{(+)}(\bar b^{(0)}\alpha b^{(0)})\end{bmatrix}.\tag{32}$$

We shall again introduce the spurion quartet S of Eq. (25) to project out the charge-nonconserving terms. The effective hadron–intermediate-boson Lagrangian is then given by

$$\begin{aligned}L'^{(h)}=&(S^\dagger)_\alpha(L^{(h)})^\alpha\\ =&W_{1/2}^{(+)}(\bar d^{(0)}\alpha d^{(-)})+W_{1/2}^{(0)}(d^{(+)}\alpha d^{(-)})\\ &+W_0^{(0)}(s^{(+)}\alpha d^{(-)})-W_0^{(+)}(\bar b^{(0)}\alpha d^{(-)})\\ &+W_{1/2}^{(+)}(\bar d^{(0)}\alpha s^{(-)})+W_{1/2}^{(0)}(d^{(+)}\alpha s^{(-)})\\ &+W_0^{(0)}(s^{(+)}\alpha s^{(-)})+W_0^{(+)}(\bar b^{(0)}\alpha s^{(-)}).\end{aligned}\tag{33}$$

Next we shall assume for case I that the universal damping of the strangeness-changing transitions is due to the breakdown of the strong-interaction symmetry. The damping factors for the charged and neutral strangeness-changing currents $(\bar d^{(0)}\alpha s^{(-)})$ and $(s^{(+)}\alpha d^{(-)})$ of $SU(3)$ are assumed to be of the order[8,10]

$$\lambda_V\approx\lambda_A\approx m_\pi/m_K=\lambda.\tag{34}$$

At present we do not have any knowledge about the damping of the charmed currents. But in the following we shall consider only the case of the $SU(3)$ limit, disregarding the damping of the $|\Delta s|=1$ transitions for case I.

We see that the intermediate boson $W_{1/2}^{(+)}$ carries the noncharmed currents, while $W_0^{(+)}$ carries the charmed currents. We also note that the assumption that $W_{1/2}^{(+)}$ (or $W_0^{(+)}$) will couple to $W_0^{(-)}$ (or $W_{1/2}^{(-)}$) with the same strength with which it is coupled to its antiparticle indicates here the maximum violation of the charm number in weak interactions.[2,5]

Case II. The hadron currents $J_\beta{}^\alpha$ and the hadron–intermediate-boson Lagrangian $L^{(h)}$ are the same as case I. Again we shall introduce the spurion quartet S' of Eq. (28) to project out the charge-nonconserving terms. The effective hadron–intermediate-boson Lagrangian is then given by

$$\begin{aligned}L'^{(h)}=&(S'^\dagger)_\alpha(L^{(h)})^\alpha\\ =&W_{1/2}^{(+)}(\bar d^{(0)}\alpha d^{(-)})\cos\theta+W_{1/2}^{(0)}(d^{(+)}\alpha d^{(-)})\cos\theta\\ &+W_0^{(0)}(s^{(+)}\alpha d^{(-)})\cos\theta-W_0^{(+)}(\bar b^{(0)}\alpha d^{(-)})\sin\theta\\ &+W_{1/2}^{(+)}(\bar d^{(0)}\alpha s^{(-)})\sin\theta+W_{1/2}^{(0)}(d^{(+)}\alpha s^{(-)})\sin\theta\\ &+W_0^{(+)}(\bar b^{(0)}\alpha s^{(-)})\cos\theta+W_0^{(0)}(s^{(+)}\alpha s^{(-)})\sin\theta,\end{aligned}\tag{35}$$

where θ is the Cabibbo angle. In the present case the damping of the currents $(\bar d^{(0)}\alpha d^{(-)})$, $(d^{(+)}\alpha s^{(-)})$, $(s^{(+)}\alpha s^{(-)})$, and $(\bar b^{(0)}\alpha d^{(-)})$ are introduced by our choice of the spurion quartet S', which is picked out in accordance with the peculiar mixing of neutrinos of Eq. (18). This suppression has nothing to do with the breakdown of the strong-interaction symmetry. The noncharmed parts of $L'^{(h)}$ are identical to those as obtained by d'Espagnat and Villachon with $\theta=\pi/2+\alpha$.

In both cases we introduce eight distinct intermediate bosons into our scheme.

VII. APPLICATIONS TO THE LEPTONIC AND NONLEPTONIC DECAYS

(i) The Purely Leptonic Decays

The purely leptonic decays are given by

$$\begin{aligned}\mathcal{H}_1=&g^2L'^{(l)\dagger}L'^{(l)},\\ =&g^2(L^{(l)\dagger})_\alpha S^\alpha(L^{(l)})^\beta(S^\dagger)_\beta.\end{aligned}\tag{36}$$

If we do not assume that the intermediate bosons $W_{1/2}^{(0)}$ and $W_0^{(0)}$ will interact with each other, the weak-interaction Hamiltonian is then, after absorbing the intermediate bosons,

$$\begin{aligned}\mathcal{H}_1=(G/\sqrt2)\{&(e^+\alpha\nu_e)(\bar\nu_e de^-)+(e^+\alpha\nu_e)(\bar\nu_\mu d\mu^-)\\ &+(\mu^+\alpha\nu_\mu)(\bar\nu_e\alpha e^-)+(\mu^+\alpha\nu_\mu)(\bar\nu_\mu\alpha\mu^-)\\ &+(e^+\alpha e^-)(e^+\alpha e^-)+(\mu^+\alpha\mu^-)(\mu^+\alpha\mu^-)\}\end{aligned}\tag{37}$$

for case I, and

$$\mathcal{H}_1=(G/\sqrt{2})\{(e^+\alpha\nu_e)(\bar{\nu}_e d e^-)+(e^+\alpha\nu_e)(\bar{\nu}_\mu\alpha\mu^-)+(\mu^+\alpha\nu_\mu)(\bar{\nu}_e\alpha e^-)+(\mu^+\alpha\nu_\mu)(\bar{\nu}_\mu\alpha\mu^-)+(e^+\alpha e^-)(e^+\alpha e^-)\cos^2\theta+(\mu^+\alpha\mu^-)(\mu^+\alpha\mu^-)\sin^2\theta\} \quad (38)$$

for case II. In both cases the weak-interaction Hamiltonian contains the processes $(e^+\alpha e^-)(e^+\alpha e^-)$ and $(\mu^+\alpha\mu^-)(\mu^+\alpha\mu^-)$ which involve only neutral currents.

If we put the angular factors to the current parts in case II, the spurion part is then for both cases

$$S_\alpha(S^\dagger)^\beta=\begin{bmatrix}0&0&0&0\\0&1&1&0\\0&1&1&0\\0&0&0&0\end{bmatrix}. \quad (39)$$

If fact, we can formulate case II in such a way that the weak currents involve proper angular factors and the spurion quartet is just given by

$$S=\begin{bmatrix}0\\1\\1\\0\end{bmatrix}\text{ for all currents.} \quad (40)$$

(ii) The Semileptonic Decays

For the semileptonic decays the weak-interaction Hamiltonian is given by

$$\mathcal{H}_2=g^2(L'^{(l)\dagger}L'^{(h)}+L'^{(h)\dagger}L'^{(l)}),$$
$$=g^2\{(L^{(l)\dagger})_\alpha S^\alpha(L^{(h)})^\beta(S^\dagger)_\beta+(L^{(h)\dagger})_\alpha S^\alpha(L^{(l)})^\beta(S^\dagger)_\beta\}. \quad (41)$$

After the intermediate bosons are absorbed, the Hamiltonian $\mathcal{H}_2$ can then be written as

$$\mathcal{H}_2=G/\sqrt{2}\{(e^+\alpha\nu_e)[(d^{(+)}\alpha d^{(0)})+(s^{(+)}\alpha d^{(0)})-(d^{(+)}\alpha b^{(0)})+(s^{(+)}\alpha b^{(0)})]+(\mu^+\alpha\nu_\mu)[(d^{(+)}\alpha d^{(0)})+(s^{(+)}\alpha d^{(0)})-(d^{(+)}\alpha b^{(0)})+(s^{(+)}\alpha b^{(0)})]+(e^+\alpha e^-)[(d^{(+)}\alpha d^{(-)})+(s^{(+)}\alpha d^{(-)})]+(\mu^+\alpha\mu^-)[(d^{(+)}\alpha s^{(-)})+(s^{(+)}\alpha s^{(-)})]\}+\text{H.c.} \quad (42)$$

for case I, and

$$\mathcal{H}_2=G/\sqrt{2}\{(e^+\alpha\nu_e)[(d^{(+)}\alpha d^{(0)})\cos\theta+(s^{(+)}\alpha d^{(0)})\sin\theta-(d^{(+)}\alpha b^{(0)})\sin\theta+(s^{(+)}\alpha b^{(0)})\cos\theta]+(\mu^+\alpha\nu_\mu)[(d^{(+)}\alpha d^{(0)})\cos\theta+(s^{(+)}\alpha d^{(0)})\sin\theta-(d^{(+)}\alpha b^{(0)})\sin\theta+(s^{(+)}\alpha b^{(0)})\cos\theta]+(e^+\alpha e^-)[(d^{(+)}\alpha d^{(-)})\cos\theta+(s^{(+)}\alpha d^{(-)})\sin\theta]+(\mu^+\alpha\mu^+)[(d^{(+)}\alpha s^{(-)})\cos\theta+(s^{(+)}\alpha s^{(-)})\sin\theta]\}+\text{H.c.} \quad (43)$$

for case II. We note that the weak-interaction Hamiltonian $\mathcal{H}_2$ is CP-invariant. If we leave aside angular factors, the spurion part is then for both cases

$$S\cdot S^\dagger=\begin{bmatrix}0&0&0&0\\0&1&1&0\\0&1&1&0\\0&0&0&0\end{bmatrix}. \quad (44)$$

The hadron currents $[(d^{(+)}\alpha d^{(0)})+(s^{(+)}\alpha d^{(0)})]$, or $[(d^{(+)}\alpha d^{(0)})\cos\theta+(s^{(+)}\alpha d^{(0)})\sin\theta]$ of the Cabibbo form, and their Hermitian conjugate are noncharmed, and transform with respect to $SU(3)$ like components of unitary octets. We see that the effective coupling constant for neutron β decay is G for case I, and is $G\cos\theta$ for case II. The charmed currents $[-(d^{(+)}\alpha b^{(0)})+(s^{(+)}\alpha b^{(0)})]$ or $[-(d^{(+)}\alpha b^{(0)})\sin\theta+(s^{(+)}\alpha b^{(0)})\cos\theta]$ and their Hermitian conjugate transform with respect to $SU(3)$ like components of unitary triplets, and will contribute to the leptonic decays of the charmed particles.[2,5]

We encounter here the problem of the absence of neutral lepton currents. In contrast to other theories,[8,18,22] only the charged lepton pairs e^+e^- and $\mu^+\mu^-$ will make their appearance in neutral currents in the present scheme. One way to overcome this difficulty is to assume that the effective coupling constant $g_{W^{(0)}l^{(+)}l^{(-)}}$ of the lepton–neutral-intermediate-boson vertex is much smaller than $g_{W^{(\pm)}l^{(\pm)}\nu}$ of the lepton–charged-intermediate-boson vertex $(g_{W^{(0)}l^{(+)}l^{(-)}}/g_{W^{(\pm)}l^{(\pm)}\nu}<10^{-2})$.[18,22] This assumption will spoil the symmetry scheme of the lepton–intermediate-boson interactions.

Here we may speculate that in the $SU(4)$ limit the leptons would be degenerate and the symmetry for the lepton–intermediate-boson interactions would be exact. Then, due to some breakdown of the $SU(4)$ symmetry which is quite independent of the symmetry breakdown for the strong interactions, the lepton masses split and there appears a suppression factor for the vertex $(W^0l^+l^-)$ which may be of the order (m_e/m_μ).[23]

(iii) The Nonleptonic Decays

The following weak-interaction Hamiltonian

$$\mathcal{H}_3=g^2(L'^{(h)\dagger}L'^{(h)})=g^2\{(L^{(h)\dagger})_\alpha S^\alpha(L^{(h)})^\beta(S^\dagger)_\beta\} \quad (45)$$

is responsible for the nonleptonic decays. If we do not assume that the intermediate bosons $W_{1/2}^{(0)}$ and $W_0^{(0)}$ will interact with each other, the Hamiltonian, after absorbing the intermediate bosons is then

$$\begin{aligned}\mathcal{H}_3=G/\sqrt{2}\{&(d^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha d^{(-)})+(d^{(+)}\alpha d^{(-)})(d^{(+)}\alpha d^{(-)})+(d^{(+)}\alpha s^{(-)})(s^{(+)}\alpha d^{(-)})\\&+(d^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha s^{(-)})+(d^{(+)}\alpha d^{(-)})(d^{(+)}\alpha s^{(-)})+(d^{(+)}\alpha s^{(-)})(s^{(+)}\alpha s^{(-)})+(s^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha d^{(-)})\\&+(s^{(+)}\alpha d^{(-)})(d^{(+)}\alpha d^{(-)})+(s^{(+)}\alpha s^{(-)})(s^{(+)}\alpha d^{(-)})+(s^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha s^{(-)})+(s^{(+)}\alpha d^{(-)})(d^{(+)}\alpha s^{(-)})\\&+(s^{(+)}\alpha s^{(-)})(s^{(+)}\alpha s^{(-)})+(d^{(+)}\alpha b^{(0)})(\bar{b}^{(0)}\alpha d^{(-)})+(b^{(+)}\alpha b^{(0)})(\bar{b}^{(0)}\alpha s^{(-)})-(s^{(+)}\alpha b^{(0)})(\bar{b}^{(0)}\alpha s^{(-)})\\&+(s^{(+)}\alpha b^{(0)})(\bar{b}^{(0)}\alpha s^{(-)})-(d^{(+)}\alpha d^{(0)})(\bar{b}^{(0)}\alpha d^{(-)})-(\bar{d}^{(0)}\alpha d^{(-)})(d^{(+)}\alpha b^{(0)})+(d^{(+)}\alpha d^{(0)})(\bar{b}^{(0)}\alpha s^{(-)})\\&-(\bar{d}^{(0)}\alpha s^{(-)})(d^{(+)}\alpha b^{(0)})-(s^{(+)}\alpha d^{(0)})(\bar{b}^{(0)}\alpha d^{(-)})+(\bar{d}^{(0)}\alpha d^{(-)})(s^{(+)}\alpha b^{(0)})+(s^{(+)}\alpha d^{(0)})(\bar{b}^{(0)}\alpha s^{(-)})\\&+(\bar{d}^{(0)}\alpha s^{(-)})(s^{(+)}\alpha b^{(0)})\}\end{aligned} \quad (46)$$

[22] A. Salam and J. C. Ward, Phys. Letters 13, 168 (1964).
[23] I am indebted to Professor R. Oehme for suggesting this point.

for case I, and

$$\begin{aligned}\mathcal{H}_3 = G/\sqrt{2}\{&[(d^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha d^{(-)})+(d^{(+)}\alpha d^{(-)})(d^{(+)}\alpha d^{(-)})+(\rho d^{(+)}\alpha s^{(-)})(s^{(+)}\alpha d^{(-)})]\cos^2\theta\\ &+[(d^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha s^{(-)})+(d^{(+)}\alpha d^{(-)})(d^{(+)}\alpha s^{(-)})+(d^{(+)}\alpha s^{(-)})(s^{(+)}\alpha s^{(-)})]\cos\theta\sin\theta\\ &+[(s^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha d^{(-)})+(s^{(+)}\alpha d^{(-)})(d^{(+)}\alpha d^{(-)})+(s^{(+)}\alpha s^{(-)})(s^{(+)}\alpha d^{(-)})]\cos\theta\sin\theta\\ &+[(s^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha s^{(-)})+(s^{(+)}\alpha d^{(-)})(d^{(+)}\alpha s^{(-)})+(s^{(+)}\alpha s^{(-)})(s^{(+)}\alpha s^{(-)})]\sin^2\theta\\ &+(d^{(+)}\alpha b^{(0)})(\bar{b}^{(0)}\alpha d^{(-)})\sin^2\theta-(b^{(+)}\alpha b^{(0)})(\bar{d}^{(0)}\alpha s^{(-)})\cos\theta\sin\theta-(s^{(+)}\alpha b^{(0)})(\bar{b}^{(0)}\alpha d^{(-)})\cos\theta\sin\theta\\ &+(s^{(+)}\alpha b^{(0)})(\bar{b}^{(0)}\alpha s^{(-)})\cos^2\theta-(d^{(+)}\alpha d^{(0)})(\bar{b}^{(0)}\alpha d^{(-)})\cos\theta\sin\theta-(\bar{d}^{(0)}\alpha d^{(-)})(d^{(+)}\alpha b^{(0)})\cos\theta\sin\theta\\ &+(d^{(+)}\alpha d^{(0)})(\bar{b}^{(0)}\alpha s^{(-)})\cos^2\theta-(\bar{d}^{(0)}\alpha s^{(-)})(d^{(+)}\alpha b^{(0)})\cos^2\theta-(s^{(+)}\alpha d^{(0)})(\bar{b}^{(0)}\alpha d^{(-)})\sin^2\theta\\ &+(\bar{d}^{(0)}\alpha d^{(-)})(s^{(+)}\alpha b^{(0)})\sin^2\theta+(s^{(+)}\alpha d^{(0)})(\bar{b}^{(0)}\alpha s^{(-)})\cos\theta\sin\theta+(\bar{d}^{(0)}\alpha s^{(-)})(s^{(+)}\alpha b^{(0)})\cos\theta\sin\theta\}\end{aligned}\quad(47)$$

for case II. We see that the Hamiltonian $\mathcal{H}_3$ for both cases contains the $|\Delta S|=0$ and $|\Delta S|=1$ transitions of ordinary hadrons, and the weak decays of charmed particles. We also note that the Hamiltonian $\mathcal{H}_3$ is CP-invariant.

Among the terms in (46) and (47), the following terms involving only the noncharmed particles are responsible for the $|\Delta S|=1$ part of the nonleptonic decays:

$$\begin{aligned}\mathcal{H}_3(|\Delta S|=1\text{ parts})&\\ =G/\sqrt{2}\{&(d^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha s^{(-)})+(d^{(+)}\alpha d^{(-)})(d^{(+)}\alpha s^{(-)})\\ &+(d^{(+)}\alpha s^{(-)})(s^{(+)}\alpha s^{(-)})+(s^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha d^{(-)})\\ &+(s^{(+)}\alpha d^{(-)})(d^{(+)}\alpha d^{(-)})+(s^{(+)}\alpha s^{(-)})(s^{(+)}\alpha d^{(-)})\}\end{aligned}\quad(48)$$

for case I, and

$$\begin{aligned}\mathcal{H}_3(|\Delta S|=1\text{ parts})&\\ =G/\sqrt{2}\{&[(d^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha s^{(-)})+(d^{(+)}\alpha d^{(-)})(d^{(+)}\alpha s^{(-)})\\ &+(d^{(+)}\alpha s^{(-)})(s^{(+)}\alpha s^{(-)})+(s^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha d^{(-)})\\ &+(s^{(+)}\alpha d^{(-)})(d^{(+)}\alpha d^{(-)})+(s^{(+)}\alpha s^{(-)})(s^{(+)}\alpha d^{(-)})]\\ &\times\cos\theta\sin\theta\}\end{aligned}\quad(49)$$

for case II.[24] The $|\Delta S|=1$ part of the nonleptonic decay will obey the $|\Delta I|=\frac{1}{2}$ rule.

Concerning the $|\Delta S|=0$ part of the nonleptonic noncharmed transitions, those terms

$$\begin{aligned}G/\sqrt{2}\{&(d^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha d^{(-)})+(d^{(+)}\alpha d^{(-)})(d^{(+)}\alpha d^{(-)})\\ &+(d^{(+)}\alpha s^{(-)})(s^{(+)}\alpha d^{(-)})+(s^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha s^{(-)})\\ &+(s^{(+)}\alpha d^{(-)})(d^{(+)}\alpha s^{(-)})+(s^{(+)}\alpha s^{(-)})(s^{(+)}\alpha s^{(-)})\}\end{aligned}\quad(50)$$

in (46) for case I and

$$\begin{aligned}G/\sqrt{2}\{&[(d^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha d^{(-)})+(d^{(+)}\alpha d^{(-)})(d^{(+)}\alpha d^{(-)})+(d^{(+)}\alpha s^{(-)})(s^{(+)}\alpha d^{(-)})]\cos^2\theta\\ &+[(s^{(+)}\alpha d^{(0)})(\bar{d}^{(0)}\alpha s^{(-)})+(s^{(+)}\alpha d^{(-)})(d^{(+)}\alpha s^{(-)})+(s^{(+)}\alpha s^{(-)})(s^{(+)}\alpha s^{(-)})]\sin^2\theta\}\end{aligned}\quad(51)$$

in (47) for case II, will consist of $|\Delta I|=1$ and $|\Delta I|=0$ components. These selection rules are the same as those of Ref. (17), but different from those of the octet enhancement.[9]

The spurion part, if we leave aside the angular factors, is then

$$S\cdot S^{\dagger}=\begin{bmatrix}0&0&0&0\\0&1&1&0\\0&1&1&0\\0&0&0&0\end{bmatrix}.\quad(52)$$

If we consider only the strangeness-changing part of the nonleptonic (noncharmed) decays, the spurion part and hence the weak-interaction Hamiltonian $\mathcal{H}_3(|\Delta S|=1$ parts) and will transform with respect to $SU(3)$ like the sixth component of a unitary octet[14,25,26]:

$$\begin{bmatrix}0&0&0\\0&0&1\\0&1&0\end{bmatrix}=\lambda_6.\quad(53)$$

We note that if we assume that $W_{1/2}^{(0)}$ and $W_0^{(0)}$ will interact, we shall get some additional terms of little interest in the weak-interaction Hamiltonians $\mathcal{H}_1$, $\mathcal{H}_2$, and $\mathcal{H}_3$.

[24] R. H. Dalitz, Varenna Lectures, 1964, Oxford (unpublished).
[25] B. W. Lee, Phys. Rev. Letters **12**, 83 (1964).
[26] H. Sugawara, Progr. Theoret. Phys. (Kyoto) **31**, 213 (1964).

VIII. CONCLUSION

We have given a unified scheme of weak interactions within the framework of $SU(4)$ by means of intermediate bosons. In this connection, we have introduced eight distinct intermediate bosons. However, we have never assumed that the $SU(4)$ symmetry is any more exact than the $SU(3)$ for the strongly interacting particles. What we have gained over the theory of d'Espagnat and Villachon is that the present theory possesses a complete symmetry between the leptons and the hadrons, and that the damping of the $|\Delta S|=1$ transitions can be introduced either through the breakdown of the strong-interaction symmetry or through a certain mixing of the unphysical neutrinos. The present scheme not only accounts for the $|\Delta I|=\frac{1}{2}$ rule, but also gives the result that the weak-interaction Hamiltonian transforms with respect to $SU(3)$ like the sixth component of a unitary octet, for the $|\Delta S|=1$ part of the nonleptonic noncharmed decays. Like other theories, we have also encountered the problem of neutral lepton currents.

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