Choice Between Primary and Dynamical $|\Delta T| = \frac{1}{2}$ Rule in the Current-Current Picture for Nonleptonic Weak Decays*

JOGESH C. PATI AND SADAO ONEDA
University of Maryland, Department of Physics and Astronomy, College Park, Maryland
(Received 7 July 1964)

The P-wave intrinsic structure of $K \to 3\pi$ decays is studied in the current-current picture for nonleptonic weak interactions, and it is shown that an accurate measurement of the asymmetry parameters of $K \to 3\pi$ decays could distinguish whether or not the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule is primary or dynamical. In case of the former, as is expected, not only the rates, but also the asymmetry parameters of $K \to 3\pi$ decays should be consistent with a dominant (i.e., apart from electromagnetism) $|\Delta\mathbf{T}| = \frac{1}{2}$ rule, while for the latter, one should expect to observe a large violation of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule in the asymmetry parameters of $K \to 3\pi$ decays with or without a similar violation in the rates. Some comments are made concerning the general necessity of enhancement of nonleptonic modes regardless of whether the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule is primary or dynamical.

I. INTRODUCTION

THE $|\Delta\mathbf{T}| = \frac{1}{2}$ rule[1] seems to be working rather well for the nonleptonic weak decays. Its origin, however, is still not understood. There have been so far essentially two different suggestions for the origin of this rule.

(A) The $|\Delta\mathbf{T}| = \frac{1}{2}$ rule is primary; i.e., the primary Lagrangian for nonleptonic weak decays of strange particles transforms as an isospinor. In such a scheme, if one wishes to maintain the current-current picture for all weak interactions, it is necessary to introduce neutral baryon currents together with charged ones. Furthermore, the observed small violations (less than 5–10% in the amplitude) of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule are to be attributed to electromagnetism. In this scheme, one might wonder why there are no neutral lepton currents.

(B) The $|\Delta\mathbf{T}| = \frac{1}{2}$ rule is dynamical[2–4]; i.e., the primary Lagrangian for nonleptonic weak decays is a mixture of $|\Delta\mathbf{T}| = \frac{1}{2}, \frac{3}{2}, \cdots$ etc., but the $|\Delta\mathbf{T}| = \frac{1}{2}$ components are enhanced relative to the other ones through some dynamical mechanism.[5] In this scheme, the observed violations of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule are to be attributed to the "weaker" $|\Delta\mathbf{T}| \neq \frac{1}{2}$ transitions,[2] and one can avoid the introduction of neutral currents. Furthermore, if one associates a strength f' with the strangeness-violating current,[2] which is weaker than the strength f associated with the strangeness-preserving one,[6] the enhancement mechanism allows us to explain simultaneously the faster rates of the nonleptonic modes together with the slower rates of the leptonic modes of strange particle decays.

It is important to ascertain which of these schemes is essentially correct. If on aesthetic grounds one would discard the presence of neutral currents in scheme (B), then one feature, which could in principle yield a direct method to distinguish between the two schemes, is the question of whether or not there exist neutral currents in the weak nonleptonic Lagrangian. In the framework of weak intermediate bosons, one has to ask whether or not there are neutral counterparts of the charged intermediate bosons (yet to be found). Unfortunately, the presence of such neutral baryon currents and/or neutral intermediate bosons is hard to establish directly for a variety of reasons. For example, weak elastic (pp), (nn), or $(\Lambda n)\cdots$ scattering with a parity-violating amplitude (that is hard to detect) is given not only by neutral currents, but also by purely charged currents together with strong interactions. Thus, in order to tell whether or not there are neutral baryon currents in addition to charged ones, it is necessary to establish the isotopic property of the above parity-violating amplitudes. As regards the neutral intermediate bosons, since they are not coupled to leptons, one has to look at the semiweak production of real W^0 by energetic pions or protons in processes such as $\pi^+ + p \to W^0 + \pi^+ + p$ or $p + p \to W^0 + p + p$, etc., with the subsequent strangeness violating decays of W^0 to $(K\pi)$ system. The cross sections for such processes [taking the branching ratio for the $(K\pi)$-decay mode of W^0 to be nearly 10%] are expected to be nearly 10^{-33} cm^2 for incident pion or proton energies of 5–6 BeV and $M_{W^0} \simeq 1.5$–2 BeV. Needless to say, if charged inter-

* Work supported in part by grants from the National Science Foundation, the United States Air Force, and the University of Maryland General Research Board.

[1] The current evidence for this rule has been reviewed by R. H. Dalitz, Proceedings of the Brookhaven International Conference on Weak Interactions, September 1963 (unpublished).

[2] S. Oneda, J. C. Pati, and B. Sakita, Phys. Rev. **119**, 482 (1960); Nucl. Phys. **16**, 318 (1960); Phys. Rev. Letters **6**, 24 (1961).

[3] A. Salam and J. C. Ward, Phys. Rev. Letters **5**, 390 (1960); A. Salam, Phys. Letters **8**, 217 (1964).

[4] M. Gell-Mann and R. P. Feynman (private communication) have often emphasized the desirability of dynamical $|\Delta\mathbf{T}| = \frac{1}{2}$ rule. See for example the discussion at the end of M. Gell-Mann, Rev. Mod. Phys. **31**, 835 (1959).

[5] There have been different suggestions regarding such dynamical mechanisms. Within the Sakata or Sakata-like models (for example), it has been demonstrated by Oneda, Pati, and Sakita (Ref. 2) that the nonleptonic weak decays may be dominated by two fermion transitions such as $\Lambda \to n$, which automatically satisfy the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule. Recently such an approach has been adopted by J. Schwinger [Bull. Am. Phys. Soc. **9**, 480 (1964) and Phys. Rev. Letters **12**, 630 (1964)]. A slightly different but equivalent approach, and one which is capable of being extended easily to a more global model, is the tadpole mechanism of Salam and Ward and Salam (Ref. 3). See also a more recent work of S. Coleman and S. L. Glashow, Phys. Rev. **134**, B681 (1964).

[6] It may be noted that in the Cabibbo scheme [N. Cabibbo, Phys. Rev. Letters **10**, 531 (1963)], f and f' correspond to $\cos\theta$ and $\sin\theta$ respectively, apart from a common multiplicative factor.

mediate bosons are found, it will be of great interest to search for their neutral counterparts with comparable mass. However, we see that until experiments along the above lines are feasible, a direct establishment of the presence or absence of neutral baryon currents may not be possible.

Coming to indirect methods, as long as the violations of the $|\Delta \mathbf{T}|=\frac{1}{2}$ rule in the amplitudes for nonleptonic decay modes are less than 5–10%, as obtained from the observed decay rates and measurements of S- and P-wave amplitudes in hyperon decays, it will also be hard to distinguish between the two schemes on the basis of rates and hyperon decay parameters. This is because in scheme (A) such violations may be attributed to rather uncertain electromagnetic corrections,[7] while in scheme (B) it is "naturally" expected.[2] Thus, one has to *examine other physical entities which may not have much effect on the rates, but may still receive significant contributions from the* $|\Delta \mathbf{T}|\neq\frac{1}{2}$ *transitions under scheme (B) that can hardly be attributed to electromagnetism under scheme (A)*.[8] The purpose of this note is to point out that the asymmetry parameter in $K\to 3\pi$ decay is precisely such a physical entity, and its accurate measurement for the various $K\to 3\pi$ modes could serve to distinguish between the two schemes. In the next section, we will be concerned with a study of the asymmetry parameter of $K\to 3\pi$ decay that arises from its intrinsic structure.

II. THE INTRINSIC STRUCTURE IN $K\to 3\pi$ DECAY

We will assume a current-current picture for nonleptonic decays with or without intermediate bosons.[9] In such a picture, the following factorization of the $K\to 3\pi$ matrix element contributes to its intrinsic structure:

$$\langle\pi\pi|J_\alpha W_\alpha|W\rangle\langle W|S_\beta{}^\dagger W_\beta{}^\dagger|K\pi\rangle, \qquad (1)$$

$$\langle\pi|J_\alpha W_\alpha|W\rangle\langle W|S_\beta{}^\dagger W_\beta{}^\dagger|K\pi\pi\rangle. \qquad (2)$$

S_β stands for the strangeness-changing, and J_φ for the strangeness-preserving, current. W denotes the intermediate boson. The charge indices have been omitted and may be filled in appropriately. If there are no intermediate bosons, (1) and (2) reduce to

$$\langle\pi\pi|J_\alpha|0\rangle\langle 0|S_\alpha{}^\dagger|K\pi\rangle, \qquad (1')$$

$$\langle\pi|J_\alpha|0\rangle\langle 0|S_\alpha{}^\dagger|K\pi\pi\rangle. \qquad (2')$$

The argument is now based on the following two observations:

(i) Under scheme (B), both (1) and (2) contain an appreciable mixture of $|\Delta \mathbf{T}|=\frac{1}{2}$ and $|\Delta \mathbf{T}|\neq\frac{1}{2}$ transitions. This is easy to see as follows: Consider, for example, that J_α transforms as an isovector, while S_β as an isospinor. Then clearly the net matrix element (1) transforms as a linear combination of $T=\frac{1}{2}$ and $\frac{3}{2}$;[10] the $\frac{3}{2}$ component cannot be eliminated with only charged currents. A similar argument applies to the matrix element (2).

(ii) The magnitude of the contribution of (1) to the asymmetry parameter of $K^+\to\pi^++\pi^0+\pi^0$ decay (for example) can be estimated reasonably well by using the known rates of $K_{e3}{}^+$ and $\pi_{e3}{}^+$ decays, and is found to be comparable to the experimental value. That of (2) can be estimated with some uncertainty by using the known rates of $K_{e4}{}^+$ and $\pi_{e2}{}^+$ decays, and may also be appreciable.

We will first estimate the contribution of (1) to the asymmetry parameter of τ' mode. The relevant Feynman diagram is shown in Fig. 1. Its matrix element with the necessary symmetrization between the two like π^0 mesons is given by[11]

$$\begin{aligned} M_{\tau'}(\text{Fig. 1}) &\simeq (2\pi)^4\delta^4(P_K-P_1-P_2-P_3)(\sqrt{2}G_W f_+/m_W{}^2) \\ &\quad\times[(P_K+P_1)\cdot(P_2-P_3)+(P_K+P_2)\cdot(P_1-P_3)]/\sqrt{2} \\ &= (2\pi)^4\delta^4(P_K-P_1-P_2-P_3)(\sqrt{2}G_W f_+/m_W{}^2) \\ &\quad\times(\sqrt{2}m_K)(-Qy), \qquad (3)\end{aligned}$$

where $\sqrt{2}G_W$ denotes the coupling constant of the W^+ meson to the $(\pi^+\pi^0)$ system,[12] m_W the mass of the W meson; P_K, P_1, P_2, and P_3 the four-momenta of the K meson, the two π^0 mesons and the π^+ meson, respectively; Q the energy release in τ' decay, and y the

[7] For example, there have been various attempts at explaining the $K^+\to\pi^++\pi^0$ rate by final-state interactions together with electromagnetism [M. L. Good and W. G. Holladay, Phys. Rev. Letters **4**, 138 (1960)], or by the $K^+\to\pi^++\eta\to\pi^++\pi^0$ mechanism [Riazzuddin and Fayyazuddin, Phys. Rev. **129**, 2337 (1963)], etc. Similarly, in the $K\to 3\pi$ decays, the mechanism $K_2{}^0\to\eta\to 3\pi$ [C. Bouchiat, J. Nuyts, and J. Prentki, Phys. Letters **3**, 156 (1963); S. Oneda and S. Hori, Phys. Rev. **132**, 1800 (1963)] may yield a somewhat larger violation of the $|\Delta\mathbf{T}|=\frac{1}{2}$ rule than usually expected on the basis of electromagnetism (a factor α/π in the matrix element). Recently, a different explanation of the $(K^+\to\pi^++\pi^0)/(K_1{}^0\to 2\pi)$ ratio has been pointed out by N. Cabibbo [Phys. Rev. Letters **12**, 62 (1964)] and M. Gell-Mann [*ibid.* **12**, 155 (1964)], who noted that $K_1{}^0\to 2\pi$ is forbidden in the limit of strict unitary symmetry for strong interactions and octet transformation property for nonleptonic weak interactions.

[8] Of course, in scheme (A), all relevant physical entities will automatically satisfy $|\Delta\mathbf{T}|=\frac{1}{2}$ to the lowest order in weak interactions, apart from electromagnetic corrections.

[9] In the framework of intermediate bosons, the current-current picture for the full nonleptonic interaction is to be looked upon as an effective interaction with a slight nonlocality. The nonlocality, especially for mass of the intermediate boson $\gtrsim$1 BeV (which seems to be the case from recent CERN experiments) is negligible for our discussion.

[10] If S_β transforms as a linear combination of $I=\frac{1}{2}$ and $\frac{3}{2}$, then the net matrix element (1) or (2) will transform as a linear combination of $I=\frac{1}{2}, \frac{3}{2}, \frac{5}{2}$, and so on.

[11] In writing Eq. (3) we have approximated the denominator of the W-meson propagator $((P_2+P_3)^2-m_W{}^2)$ by $(-m_W{}^2)$. It is easy to see from the kinematics of $K\to 3\pi$ decays that $(P_2+P_3)^2\ll m_W{}^2$ especially for mass of the W meson $\gtrsim$ 1 BeV, which is indicated from recent CERN experiments. We will adopt the same approximation in the rest of this paper in writing other matrix elements with intermediate vector meson.

[12] The coupling is given by $(\sqrt{2}G_W)(\varphi_{\pi^+}{}^*\partial_\mu\varphi_{\pi^0}-\varphi_{\pi^0}\partial_\mu\varphi_{\pi^+}{}^*)W_\mu{}^+ +\text{H.C.}$ Note that the coupling of W^+ to the $(\bar{\nu}e)$ or $(\bar{p}n)$ vector current is given by just G_W. This is the content of the conserved vector current hypothesis, which is consistent with the observed rates of O^{14} and $\pi_{e3}{}^+$ decays.

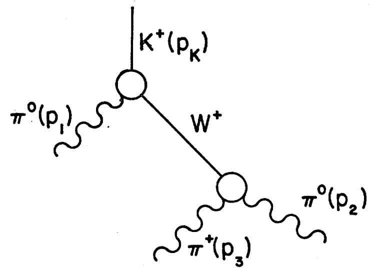

FIG. 1. Feynman diagram contributing to the asymmetric component of τ' decay coming from the factorization of the currents corresponding to (1). W^+ denotes the intermediate vector meson.

Dalitz variable $(3T_3-Q)/Q$, T_3 being the kinetic energy of the unlike meson (π^+). f_+ denotes the form factor of K_{e3}^+ decay,[13] and is given in terms of K_{e3}^+ rate by

$$W(K_{e3}^+)\approx\frac{m_\pi^5(m_K/m_\pi)[G_Wf_+/m_W^2]^2\times(2.16)}{(2\pi)^3}. \quad (4)$$

Using the observed rate $W(K_{e3}^+)\approx 4.1\times 10^6$ (sec^{-1}),[14] we obtain

$$|G_Wf_+/m_W^2|\approx(2.5\times10^{-8})m_\pi^{-2}. \quad (5)$$

If we write the complete τ' matrix element as

$$M_{\tau'}=(2\pi)^4\delta^4(P_K-P_1-P_2-P_3)C_{\tau'}(1+A_{\tau'}y), \quad (6)$$

the τ' rate is essentially given by[15]

$$W(\tau')\simeq\frac{|C_{\tau'}|^2(m_\pi^2/m_K)(0.21)}{128\pi^3}. \quad (7)$$

So the observed τ' rate $W(\tau')\simeq 1.39\times10^6$ (sec^{-1}),[14] yields

$$|C_{\tau'}|\simeq 0.69\times10^{-6}. \quad (8)$$

From Eqs. (3), (5), (6), and (8), the contribution of Fig. 1 to $A_{\tau'}$ is

$$|A_{\tau'}(\text{Fig. 1})|=\left|\left(\frac{\sqrt{2}G_Wf_+}{m_W^2}\right)\frac{\sqrt{2}m_KQ}{C_{\tau'}}\right|$$
$$\approx 0.15, \quad (9)$$

which may be compared with the observed value[1]

$$A_{\tau'}(\text{exptl.})\approx -0.30\pm0.18. \quad (10)$$

Thus, although we cannot predict the sign, the magnitude of the asymmetry parameter of τ' mode given by (1) is close to the observed value.[16]

[13] Note that the f_- form factor of K_{l3} decay does not contribute to $K\to3\pi$ decays via Fig. 1.
[14] M. Roos, Data on Elementary Particles and Resonant States, November 1963 (unpublished); Nucl. Phys. **52**, 1 (1964).
[15] The contribution of the asymmetric $A_{\tau'}$ term to the rate is negligible.
[16] The fact that the intrinsic structure (1) could lead to a large value of the asymmetry parameter in $K\to3\pi$ decay had been noted by one of us (J.C.P.) together with M. A. Baqi-Bég (unpublished).

We will next make an order-of-magnitude estimate of the contribution of (2) to the $K\to3\pi$ asymmetry parameter. Since only the rate of $K^+\to\pi^++\pi^-+e^++\nu$ (and not that of $K^+\to\pi^0+\pi^0+e^++\nu$) is known, and since we are interested only in knowing the order of magnitude of such structure as given by (2), we will estimate its contribution to the τ mode. The relevant diagram is shown in Fig. 2.

If we write the $K^+\to\pi^++\pi^-+e^++\nu$ matrix element in the form[17]

$$M(K_{e4}^+)=(2\pi)^4\delta^4(P_K-P_{\pi^+}-P_{\pi^-}-P_{e^+}-P_\nu)\times\left(\frac{G_W}{m_W^2}\right)\left(\frac{1}{m_P}\right)[N_1P_{\pi^+\mu}+N_2(P_{e^+}+P_\nu)_\mu+N_3P_{\pi^-\mu}]\bar\nu\gamma_\mu(1+i\gamma_5)e \quad (11)$$

and the $\pi^+\to e^++\nu$ matrix element as

$$M(\pi_{e2}^+)=(2\pi)^4\delta^4(P_{\pi^+}-P_{e^+}-P_\nu)F_\pi\times\left(\frac{G_W^2}{m_W^2}\right)(m_P)P_{\pi^+\mu}\bar\nu\gamma_\mu(1+i\gamma_5)e, \quad (12)$$

where N_1, N_2, N_3, and F_π are diminsionless Lorentz-invariant scalars, then the matrix element of Fig. 2 with the necessary symmetrization between the two like π^+ mesons is given by

$$M_\tau(\text{Fig. 2})=(2\pi)^4\delta^4(P_K-P_1-P_2-P_3)\times\left(\frac{G_W}{m_W^2}\right)\left(\frac{F_\pi}{\sqrt{2}}\right)[2N_1P_1\cdot P_2+2N_2m_\pi^2+N_3P_3\cdot(P_1+P_2)]. \quad (13)$$

Writing the complete τ-decay matrix element in a form analogous to (6),

$$M_\tau=(2\pi)^4\delta^4(P_K-P_1-P_2-P_3)C_\tau[1+A_\tau y], \quad (14)$$

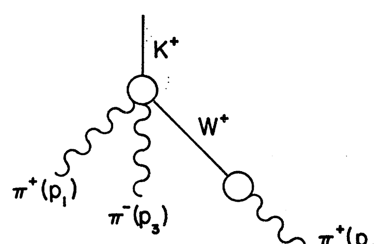

FIG. 2. Feynman diagrams contributing to both the symmetric and asymmetric components of τ decay coming from the factorization of the currents corresponding to (2). W^+ denotes the intermediate vector meson.

[17] In writing Eq. (11) we have dropped the term

$$\epsilon_{\mu\nu\rho\sigma}p_{K^+\nu}p_{\pi^+\rho}p_{\pi^-\sigma}/m_p^2$$

whose contribution to the K_{e4}^+ rate is negligible compared to the other terms, and which does not contribute to the matrix element of Fig. 2 anyway.

it is easy to check that the contribution of Fig. 2 to A_τ is

$$|A_\tau(\text{Fig. 2})|=\left|\frac{1}{C_\tau}\left(\frac{G_W}{m_W{}^2}\right)(N_3-2N_1)\left(\frac{F_\pi}{\sqrt{2}}\right)\left(\frac{Q}{3}\right)\right|. \quad (15)$$

The observed rates of τ decay[14] and $\pi^+\to e^++\nu$ decay[18] yield

$$|C_\tau|\simeq 1.38\times 10^{-6}$$

and

$$|F_\pi|\simeq 0.14. \quad (16)$$

It is not possible to obtain N_1 and N_3 unambiguously just from the observed rate of $K_{e4}{}^+$ decay. However, since we are interested only in an order-of-magnitude estimate, let us first use the perturbation-theoretic result,[19] which gives $N_3\ll N_1$. Thus, if we drop the N_3-term and note that the contribution of N_2 term is proportional to m_e (and hence may be dropped), the $K_{e4}{}^+$ rate is given by[19]

$$W(K_{e4}{}^+)\simeq\frac{(G_W/m_W{}^2)^2}{m_P{}^2}\left(\frac{m_\pi{}^7}{64\pi^5}\right)[0.02|N_1|^2]. \quad (17)$$

Thus, the observed value[20] of $W(K_{e4}{}^+)\simeq(2.1\pm0.5)\times 10^3\ \text{sec}^{-1}$ yields

$$|(G_W/m_W{}^2)N_1|\simeq(6.6\times10^{-7})m_\pi{}^{-2}. \quad (18)$$

Using this value only as an order-of-magnitude estimate,[21] and allowing for the possibility that N_3 may be of the same order of magnitude as N_1 with arbitrary relative sign [so that $|N_3-2N_1|\simeq(0\text{–}3)|N_1|$], we have from Eqs. (15), (16), and (18)

$$|A_\tau(\text{Fig. 2})|\simeq(0\text{–}3)[2.4\times10^{-2}]. \quad (19)$$

Comparing this with the observed value[1] A_τ(exptl.) $\approx 0.14\pm0.02$, we notice that the contribution of Fig. 2 to the τ-asymmetry parameter, although uncertain, may be appreciable.

Thus, we have shown that *there exist mechanisms such as (1), and maybe even (2)*, which lead to rather large magnitude for the asymmetry parameter in $K\to 3\pi$ decays, and which do not satisfy the $|\Delta\mathbf{T}|=\frac{1}{2}$ rule in scheme (B). In addition to such intrinsic structure, there are nonintrinsic or dynamical mechanisms such as $K\to\rho+\pi\to 3\pi$ and $K\to K^*+\pi\to 3\pi$, etc.,[22] which also contribute to the asymmetry parameter. In this note, we are *not* concerned with an over-all estimate of the asymmetry parameters in $K\to 3\pi$ decays. But the point to note is that such *nonintrinsic* structure can proceed through the enhancement mechanism discussed under scheme (B), and hence, will *predominantly satisfy* $|\Delta\mathbf{T}|=\frac{1}{2}$. Thus, if we superimpose the intrinsic structures (1) and (2) on the nonintrinsic mechanisms, we could expect (barring the possibility of accidental cancellation of the $|\Delta\mathbf{T}|\neq\frac{1}{2}$ transitions) that under scheme (B) there should be an appreciable violation of the $|\Delta\mathbf{T}|=\frac{1}{2}$ rule in the asymmetry parameter of $K\to 3\pi$ decays which can hardly be attributed to electromagnetism in scheme (A).

Next one might ask: Will the mechanisms (1) and (2) lead to a significant violation of the $|\Delta\mathbf{T}|=\frac{1}{2}$ rule [under scheme (B)] in the rates as well? Our answer to this question is not definite. First, note that (1) contributes only to the asymmetric term in Eq. (6) [see Eq. (3)], and hence, negligibly to the rate. However, (2) does contribute to the symmetric part C_τ, and hence, to the rate. This contribution is[19]

$$C_\tau(\text{Fig. 2})=\left(\frac{F_\pi}{\sqrt{2}}\right)\left(\frac{G_W}{m_W{}^2}\right)\times[m_K{}^2N_1+m_\pi{}^2(2N_2-N_1-N_3)+m_K(m_\pi+\tfrac{1}{3}Q)(N_3-2N_1)]. \quad (20)$$

It is hard to estimate the right-hand side of (20) owing to the uncertainty in the relative signs of N_1, N_2, and N_3 and their magnitudes. If we again use perturbation theory results[19] ($N_1\simeq N_2$; $N_3\ll N_1$), just as a guide for order-of-magnitude estimates, then, using Eq. (18) for the value of $|N_1|$, we have

$$|C_\tau(\text{Fig. 2})|\approx 2.4\times10^{-7}. \quad (21)$$

This is nearly 16% of the observed value of C_τ [Eq. (16)]. One should regard this only as a very rough estimate, which could be wrong by even a factor of 3. So one could only say that depending upon the relative signs and magnitudes of the form factors N_1, N_2, and N_3, Fig. 2 may or may not lead to a significant violation of the $|\Delta\mathbf{T}|=\frac{1}{2}$ rule [under scheme (B)] in the $K\to 3\pi$ decay rates.

[18] E. Di Capua, R. Garland, L. Pondiom, and A. Strelzoff, Phys. Rev. **133**, B1333 (1964).

[19] J. C. Pati, S. Oneda, and B. Sakita, Nucl. Phys. **16**, 318 (1960); J. C. Pati, thesis, University of Maryland, 1960 (unpublished).

[20] R. W. Birge, R. P. Ely, G. Gidal, G. E. Kalmus *et al.*, Phys. Rev. Letters **11**, 35 (1963).

[21] It may be noted that if we use the idea of partially conserved current in the sense that the divergence of the strangeness changing current is proportional to the Kaon field, as used by Riazuddin and Zimmerman [Phys. Rev. **135**, B1211 (1964)]; the form factors N_1 and N_3 are zero, only $N_2\neq0$. This will imply that Fig. 2 does not contribute to the asymmetry parameter. However, this will be in contradiction with the observed $K_{e4}{}^+$ rate, since the contribution of N_2 term to the $K_{e4}{}^+$ rate is proportional to $m_e{}^2$ and hence very small.

[22] M. A. Baqi Bég and P. C. DeCelles, Phys. Rev. Letters **8**, 46 (1962); Riazuddin and Fayyazuddin, *ibid.* **7**, 464 (1961); G. Barton and S. P. Rosen, *ibid.* **8**, 414 (1962); C. Kacser, Phys. Rev. **130**, 355 (1963). The discussion of this nonintrinsic asymmetric component of $K\to 3\pi$ decay in the framework of eightfold way has been studied thoroughly in pion-pole approximation by S. Hori, S. Oneda, S. Chiba, and A. Wakasa, Phys. Letters **5**, 339 (1963) and S. Oneda, Y. S. Kim, and D. Korff, University of Maryland, Technical Report No. 385 (to be published). See also E. Eborlo and S. Iwao (to be published).

III. CONCLUSION

The foregoing discussion allows us to conclude:

(a) If not only the rates, but also the asymmetry parameter in $K \to 3\pi$ decays are found to be consistent with the predictions of the dominant $|\Delta\mathbf{T}| = \frac{1}{2}$ rule,[23] then it will be hard to understand it on the basis of scheme (B), and scheme (A) should certainly be favored.

(b) On the other hand, if there is a large violation[24] of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule (that cannot be expected from electromagnetism) in the asymmetry parameters of $K \to 3\pi$ decays with or without a similar violation in the rates, then scheme (B) is to be favored.

At the moment, the experiments, especially on the asymmetry parameters of τ' and $K_2^0 \to \pi^+ + \pi^- + \pi^0$ modes and the rate of $K_2^0 \to \pi^+ + \pi^- + \pi^0$ mode, which are crucial for a test of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule, are not accurate enough to distinguish between schemes (A) and (B). We therefore think it will be extremely valuable to test the degree of validity of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule in $K \to 3\pi$ decays by more precise measurements, especially on the $(+00)$ and $(+-0)$ modes.

IV. FURTHER COMMENTS

We would like to add the following relevant comments.

(1) First of all, we note that the intrinsic structures given by (1) and (2) do not arise if we abandon the current-current picture[25] for the nonleptonic decay interaction. In this case, therefore, the arguments developed in this note as regards the distinction between schemes (A) and (B) on the basis of $K \to 3\pi$ asymmetry parameters do not follow.

(2) Secondly, even if scheme (A) turns out to be the true picture, we feel that the essential idea of dynamical enhancement[5] for nonleptonic decays should still be correct, provided we wish to correlate the leptonic and nonleptonic decay interactions in some manner. This is because the leptonic decays of strange particles demand a weaker coupling constant ff' (barring the possibility of large renormalization effects), which has to be compensated for by some enhancement mechanisms to explain the "fast" nonleptonic rates.[26]

(3) Thirdly, in the scheme of unitary symmetry for strong and weak interactions, the enhancement mechanism for nonleptonic decays (mentioned above) could also lead to an enhancement of the octet channel compared to the 27-fold channel.[27] This may happen in either scheme (A) or (B). In scheme (A), one will still have the exact (apart from electromagnetism) $|\Delta\mathbf{T}| = \frac{1}{2}$ rule, while in scheme (B), one will have the predominant $|\Delta\mathbf{T}| = \frac{1}{2}$ rule; but in both cases, the dominant transition will belong to the octet representation of SU(3) which automatically satisfies the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule for the nonleptonic decays.

(4) Finally, to the extent that the intrinsic structures (1) and (2) are present in $K \to 3\pi$ decays, which are not available for $\eta \to 3\pi$ decay, one should expect to observe some difference in the spectra of $K \to 3\pi$ and $\eta \to 3\pi$ decays,[28] again within the current-current picture for nonleptonic decays.

ACKNOWLEDGMENTS

We would like to thank Professor C. Kacser for helpful discussions. J. C. Pati would also like to thank Professor W. E. Brittin for his hospitality at the Summer Institute of Theoretical Physics held at Boulder, Colorado, where part of this manuscript was prepared.

[23] For a list of predictions of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule on the rates and asymmetry parameters of $K \to 3\pi$ decays and a discussion of the present experimental situation, see R. H. Dalitz (Ref. 1). The importance of measuring the asymmetry parameters as a test of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule was first stressed by S. Weinberg, Phys. Rev. Letters 4, 87 and 585 (1960). Our aim in this paper is to point out that it is also useful to give the origin of this rule.

[24] By large violation of the $|\Delta\mathbf{T}| = \frac{1}{2}$ rule, we mean presence of $|\Delta\mathbf{T}| \neq \frac{1}{2}$ amplitude which is $\gtrsim 20$–30% (say) of the $|\Delta\mathbf{T}| = \frac{1}{2}$ amplitude. Such a violation will be almost beyond the range of electromagnetic corrections.

[25] To do this in the framework of intermediate bosons for leptonic decays, one has to require that the intermediate bosons for strangeness-preserving and strangeness-violating leptonic decays are not the same.

[26] To elaborate on this a little further, let us note that the strangeness-violating leptonic decays require f' to be nearly four times smaller than f (see, for example, N. Cabibbo, Ref. 6), where f^2 determines the neutron β-decay coupling constant. A typical nonleptonic decay $\Lambda \to P + \pi^-$ arises from the interaction $ff' J_\lambda S_\lambda^\dagger + \text{H.C.}$ where J_λ is the strangeness-preserving current $(=\bar{n}\gamma_\lambda(1+i\gamma_5)P+\cdots)$ and S_λ the strangeness-changing current $(=\bar{\Lambda}\gamma_\lambda(1+i\gamma_5)P+\cdots)$. The structure of J_λ and S_λ will be fixed by leptonic decays. If we consider the simple mechanism $ff'\langle\pi^-|J_\lambda|0\rangle\langle 0|S_\lambda^\dagger|\bar{P}\Lambda\rangle$ for the $\Lambda \to P + \pi^-$ amplitude, then it is known (Ref. 19) that one obtains a rate which is 20–30 times smaller than the observed rate. Thus there should exist some mechanism (as, for instance, the enhancement mechanism sketched in Ref. 5) which should enhance the nonleptonic decay amplitudes as compared to the simple mechanism given above, and which should explain the observed "fast" rates of nonleptonic decays in spite of the smallness of ff'.

[27] This point has also been noted by M. Gell-Mann, Phys. Rev. Letters 12, 155 (1964).

[28] L. M. Brown and P. Singer [Phys. Rev. **133**, B812 (1964)] have proposed that the asymmetries in both the K and $\eta \to 3\pi$ decays may be explained simultaneously by the existence of the dipion with mass ≈ 390 MeV and width ≈ 75 MeV. However, as discussed above in the current-current picture for nonleptonic interaction, it will be an oversimplification to neglect the contribution due to intrinsic structure for the $K \to 3\pi$ decay. As regards the contribution of vector meson resonance states to the asymmetric components, there seems to be a large difference in the two decays under consideration if we use the eightfold way symmetry limit and the pion-pole approximation. See S. Hori *et al.* and S. Oneda *et al.*, Ref. 22. Therefore, we do not feel that there is a simple relation between the spectra of two decay modes.