

Charge Properties of the K Meson and Hyperon Decay Interaction*

R. F. SAWYER†
CERN, Geneva, Switzerland
 (Received August 13, 1958)

The question of the ΔT involved in strange-particle decays is discussed in terms of universal Fermi interactions. The fundamental interactions considered contain $\Delta T > \frac{1}{2}$ as suggested by both experimental and purely theoretical considerations. It is found that by assuming global symmetry in both the pion coupling and the weak coupling one may restrict the ΔT to $\frac{1}{2}$ in a class of processes involved in hyperon decay. These are the processes in which the real pion is given off externally. A symmetry may also be incorporated which forbids the decay $\Xi^- \rightarrow N + \pi$. A breakdown of this symmetry is necessary to allow Σ^- decay. Reasons are developed for this breakdown to be manifested primarily in the P -wave part of Σ and Λ decay. A consequence is that Σ^- decay should allow no parity nonconservation. The assumption of global symmetry enables one to connect Σ decay to Λ decay. Fitting the decay rates in the suggested model yields a prediction of the Λ decay rate and asymmetry in agreement with experiment. Various ways of obtaining a selection rule prohibiting the θ^+ mode of K decay are discussed. These depend on symmetries which may be incorporated into an interaction containing $\Delta T = \frac{1}{2}, \frac{3}{2},$ and $\frac{5}{2}$.

I. INTRODUCTION

IT has been suggested that the interaction responsible for all weak processes is constructed from a vector and pseudovector "current," J_μ , in the manner¹⁻³

$$\mathcal{L}_w = \lambda J_\mu^\dagger J_\mu, \quad (1)$$

where J_μ creates one unit of electric charge, annihilated by J_μ^\dagger . This current is to include contributions from nucleon-nucleon, lepton-lepton, hyperon-hyperon, and hyperon-nucleon pairs of Fermi fields. The last is to account for the decays of K mesons and hyperons. It will be assumed here that there are no boson current terms except possibly the pion contribution to the vector current suggested by Feynman and Gell-Mann.¹ There exists much freedom in the introduction of the hyperons into J_μ . In what follows, an attempt will be made to see how the exact form of the hyperon terms may be connected to hyperon and K -meson decay data.

Assumption of such a form for the weak coupling already limits somewhat the isotopic transformation properties of the weak coupling, so much discussed recently.⁴ For example, the property $\Delta T = \frac{1}{2}$ may not be achieved in an interaction of the form (1) in which the current J_μ has no charge-conserving component, that is, in which there is always charge transferred between the two factors J . If higher ΔT are truly present in the fundamental interaction, then it is of interest to see whether there is a mechanism available to restrict the ΔT observed in hyperon decay to $\frac{1}{2}$ (though it is not necessary for this to be so, even for Λ decay).

This may be accomplished, with a suitable weak coupling, under the following assumptions:

* National Science Foundation Postdoctoral Fellow.

† Based on part of a Ph.D. thesis submitted to Harvard University in May, 1958.

¹ R. P. Feynman and M. Gell-Mann, *Phys. Rev.* **109**, 193 (1958).

² J. Schwinger, *Ann. Phys.* **2**, 407 (1957).

³ E. C. G. Sudarshan and R. E. Marshak, *Phys. Rev.* **109**, 1860 (1958).

⁴ M. Gell-Mann and A. Rosenfeld, *Annual Review of Nuclear Science* (Annual Reviews, Inc., Stanford, 1957), Vol. 7, p. 407.

(1) The strong pion coupling has global symmetry.^{2,5} The heavy fermion mass splitting will be assumed to result from the K -meson interaction.

(2) Certain K corrections to the decay process may be ignored.

(3) The final, real pion is emitted externally to a more fundamental decay process, $(\Lambda, \Sigma) \rightarrow$ nucleon.

The last assumption seems reasonable for the P -wave part of the transition amplitude, where the external pion emissions produce a $1/\omega$ dependence on the pion energy. Here the situation is analogous to low-energy bremsstrahlung. For the S wave it is an assumption motivated merely by the desire to achieve in a simple way the rule $\Delta T = \frac{1}{2}$, suggested by the branching ratio in Λ decay.

A symmetry principle will be found to exist which forbids direct decay of the Ξ into a nucleon plus a pion. Further consequences of this symmetry will be examined in the light of the above model and the experimental data.

The other half of the ΔT question relates to finding a selection rule to explain the long lifetime of the θ^+ mode. It is found that some of the symmetries mentioned above may be utilized to forbid θ^+ weakly while allowing $\Delta T = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}$ in the weak interaction. Thus no restriction is placed on the branching ratio. This selection rule will be broken down by the K coupling.

II. THE STRONG INTERACTIONS

Following the notation of Schwinger,² the N and Ξ fields will be combined into one four-component isotopic spinor $\psi_{\frac{1}{2}}$ which annihilates one unit of heavy particle charge and has the components (in terms of the particles annihilated)

$$\begin{pmatrix} i2^{-\frac{1}{2}}(\psi_{N^+} + \psi_{\Xi^-}) \\ 2^{-\frac{1}{2}}(-\psi_{N^0} + \psi_{\Xi^0}) \\ i2^{-\frac{1}{2}}(\psi_{N^0} + \psi_{\Xi^0}) \\ 2^{-\frac{1}{2}}(\psi_{N^0} - \psi_{\Xi^0}) \end{pmatrix}. \quad (2)$$

⁵ M. Gell-Mann, *Phys. Rev.* **106**, 1296 (1957).

The Λ and Σ fields are combined into

$$\psi_{1,0} = (\psi_1^2, \psi_2^2, \psi_3^2, \psi_\Lambda),$$

with the usual isotopic vector components for Σ . The following two sets of matrices are defined:

$$\begin{aligned} \tau_1 &= \begin{pmatrix} 0 & 0 & 0 & -i \\ 0 & 0 & -i & 0 \\ 0 & i & 0 & 0 \\ i & 0 & 0 & 0 \end{pmatrix}, & \tau_2 &= \begin{pmatrix} 0 & 0 & i & 0 \\ 0 & 0 & 0 & -i \\ -i & 0 & 0 & 0 \\ 0 & i & 0 & 0 \end{pmatrix}, \\ \tau_3 &= \begin{pmatrix} 0 & -i & 0 & 0 \\ i & 0 & 0 & 0 \\ 0 & 0 & 0 & -i \\ 0 & 0 & i & 0 \end{pmatrix}, & \zeta_1 &= \begin{pmatrix} 0 & 0 & 0 & i \\ 0 & 0 & -i & 0 \\ 0 & i & 0 & 0 \\ -i & 0 & 0 & 0 \end{pmatrix}, \\ \zeta_2 &= \begin{pmatrix} 0 & 0 & i & 0 \\ 0 & 0 & 0 & i \\ -i & 0 & 0 & 0 \\ 0 & -i & 0 & 0 \end{pmatrix}, \\ \zeta_3 &= \begin{pmatrix} 0 & -i & 0 & 0 \\ i & 0 & 0 & 0 \\ 0 & 0 & 0 & i \\ 0 & 0 & -i & 0 \end{pmatrix}. \end{aligned} \quad (3)$$

Their rules of multiplication are

$$\begin{aligned} \tau_i \tau_j &= \delta_{ij} + i \epsilon_{ijk} \tau_k, \\ \zeta_i \zeta_j &= \delta_{ij} + i \epsilon_{ijk} \zeta_k, \\ [\tau_i, \zeta_j] &= 0. \end{aligned} \quad (4)$$

The operators giving the heavy fermion contribution to the electric charge and the isotopic spin are

$$\begin{aligned} Q &= \bar{\psi}_{1,0} \gamma_0 [(\tau_3 + \zeta_3)/2] \psi_{1,0} + \bar{\psi}_3 \gamma_0 [(\tau_3 + \zeta_3)/2] \psi_3, \\ T_i &= \bar{\psi}_{1,0} \gamma_0 [(\tau_i + \zeta_i)/2] \psi_{1,0} + \bar{\psi}_3 \gamma_0 (\tau_i/2) \psi_3. \end{aligned}$$

The infinitesimal isotopic rotation is given by

$$\begin{aligned} \psi_3 &\rightarrow (1 + \frac{1}{2} i \delta \omega \cdot \boldsymbol{\tau}) \psi_3, \\ \psi_{1,0} &\rightarrow [1 + \frac{1}{2} i \delta \omega \cdot (\boldsymbol{\tau} + \boldsymbol{\zeta})] \psi_{1,0}. \end{aligned} \quad (5)$$

The universal pion coupling in this notation is

$$\mathcal{L}_\pi = g (\bar{\psi}_{1,0} \gamma_5 \boldsymbol{\tau} \psi_{1,0} + \bar{\psi}_3 \gamma_5 \boldsymbol{\tau} \psi_3) \varphi_\pi^i, \quad (6)$$

which has many symmetries beyond charge independence.² An important one for our purpose is the symmetry

$$\psi_{1,0,\frac{1}{2}} \rightarrow (1 + i \delta \omega \zeta_3) \psi_{1,0,\frac{1}{2}} \quad (7)$$

implying conservation of the quantity Z_3 ,

$$Z_3 = \bar{\psi}_{1,0} \gamma_0 (\zeta_3/2) \psi_{1,0} + \bar{\psi}_3 \gamma_0 (\zeta_3/2) \psi_3. \quad (8)$$

$Z_3 = +\frac{1}{2}$ in a one-nucleon state and $-\frac{1}{2}$ for a cascade particle. $Z_3 = +\frac{1}{2}$ for Σ^+ and for the "nucleon-like" combination of Σ^0 and Λ^0 . $Z_3 = -\frac{1}{2}$ for Σ^- and the cascade-like combination of Σ^0 and Λ^0 .

III. THE WEAK INTERACTION

The universal pion coupling supplies a natural definition of universality in the weak interaction, that is, \mathcal{L}_w is to be made symmetrical between ψ_3 and $\psi_{1,0}$ as is \mathcal{L}_π . The current, J_μ , which increases the charge by one unit is made up of pairs of Fermi fields connected by a

charge-raising matrix. A complete set of charge-raising matrices in our notation are

$$\begin{aligned} \tau_+ &= (\tau_1 + i\tau_2)/2, & \zeta_+ &= (\zeta_1 + i\zeta_2)/2, \\ \tau_+ \tau_3, & & \zeta_+ \tau_3, \\ \tau_+ \zeta_3, & & \zeta_+ \zeta_3, \\ \tau_+ \tau_3 \zeta_3, & & \zeta_+ \tau_3 \zeta_3. \end{aligned} \quad (9)$$

In that part of the current linking $\bar{\psi}_3$ with ψ_3 , the ζ_+ terms are not admissible since they mix nucleon and cascade particles, giving decays such as $\Xi \rightarrow N + e + \nu$. This may be seen by noting that the unitary transformation $U^{-1} \psi U = i \zeta_+ \psi$ reflects the quantity Z_3 which distinguishes N and Ξ . It will be assumed that the matrix τ_+ will be used also in the terms $\bar{\psi}_{1,0} \gamma_\mu \cdots \psi_{1,0}$, $\bar{\psi}_{1,0} \gamma_\mu \cdots \psi_3$, and $\bar{\psi}_3 \gamma_\mu \cdots \psi_{1,0}$. The quantity Z_3 will then be conserved in the weak interaction and $\Xi \rightarrow N + \pi$ therefore forbidden.

The simplest interaction of this kind utilizes only the matrix τ_+ for J_μ and τ_- for J_μ^\dagger . We write (1) as

$$\mathcal{L}_w = \lambda J_\mu^i J_\mu^i, \quad i = 1, 2 \quad (10)$$

where

$$\begin{aligned} J_\mu^i &= \bar{\psi}_{1,0} \gamma_\mu (1 + i\gamma_5) \tau_i \psi_{1,0} + \bar{\psi}_3 \gamma_\mu (1 + i\gamma_5) \tau_i \psi_{1,0} \\ &\quad + \bar{\psi}_{1,0} \gamma_\mu (1 + i\gamma_5) \tau_i \psi_3 + \bar{\psi}_3 \gamma_\mu (1 + i\gamma_5) \tau_i \psi_3. \end{aligned}$$

In this case \mathcal{L}_w contains $\Delta T = \frac{1}{2}, \frac{3}{2}$, and $\frac{5}{2}$. This has been verified by direct decomposition of \mathcal{L}_w into terms which transform irreducibly under the isotopic rotation.

IV. HYPERON DECAY

If the final pion is indeed given off externally, Λ or Σ decay corresponds to the transition $(\Lambda, \Sigma) \rightarrow N$ followed by or preceded by a pion emission. An effective weak interaction for the first part, including all pion effects, may be written

$$\mathcal{L}_{\text{eff}} = \bar{\psi}_3 [f(\gamma p) + \gamma_5 g(\gamma p)] \psi_{1,0}. \quad (11)$$

Here $f(\gamma p)$ and $g(\gamma p)$ are charge-conserving matrices in the four-dimensional isotopic space. The first term is responsible for decay into a P state; the second for the S wave. We are here not attempting to predict the relative strength of the S and P amplitudes. We observe only that the assumption of global symmetry in \mathcal{L}_π and the fundamental weak coupling (10) dictates the use of the unit matrix in the four-dimensional isotopic space for the functions f and g . To prove this, note that none of the matrices ζ_i enters the theory either through the pion coupling or the weak coupling. In view of this and the multiplication laws (4), insuring that no ζ 's may be created, the charge-conserving matrices (commuting with $\tau_3 + \zeta_3$) which may enter (11) are restricted to unity and τ_3 . Both the weak coupling and \mathcal{L}_π have the symmetry

$$\psi_3 \rightarrow i\tau_1 \psi_3, \quad \psi_{1,0} \rightarrow i\tau_1 \psi_{1,0}, \quad \varphi_\pi \rightarrow (1 - 2t_1^2) \varphi_\pi.$$

Under this operation $\psi_3 \cdots \tau_3 \psi_{1,0}$ changes sign and therefore cannot be contained in \mathcal{L}_{eff} .

That $\bar{\psi}_3 \cdots 1\psi_{1,0}$ is a $\Delta T = \frac{1}{2}$ form may be seen from the form of the infinitesimal isotopic rotation,

$$\begin{aligned} \psi_{1,0} &\rightarrow [1 + \frac{1}{2}i\delta\omega \cdot (\boldsymbol{\tau} + \boldsymbol{\zeta})]\psi_{1,0}, \\ \bar{\psi}_3 &\rightarrow \bar{\psi}_3[1 - \frac{1}{2}i\delta\omega \cdot \boldsymbol{\tau}], \\ \mathcal{L}_{\text{eff}} &\rightarrow \bar{\psi}_3 \cdots (1 + \frac{1}{2}i\delta\omega \cdot \boldsymbol{\zeta})\psi_{1,0}, \end{aligned}$$

and the fact that the ζ 's generate a $T = \frac{1}{2}$ representation of this group.

The matrix element for $\Lambda, \Sigma \rightarrow N + \pi$ is now written in the form $\xi_i^\dagger M_i \eta_{1,0}$, where i is the isotopic vector index for the pion. ξ and η are four-dimensional isotopic spinors for the initial hyperon and the final nucleon. If the interaction \mathcal{L}_{eff} [Eq. (11)] and the symmetric pion coupling are all that are present, the matrix M_i must be proportional to τ_i . [With the original weak coupling (10), M_i could have been a combination of τ_i and $\delta_{i3}\tau_3$.]

Having found no reason for the S -wave amplitude to be a sensitive function of the hyperon mass differences or coupling constants, that is, sensitive to a small breakdown in the symmetries, we shall assume the S -wave matrix element to be given by the matrix element of τ_i and the simplest energy dependence,

$$M_i = \text{const} \times \omega^{-\frac{1}{2}} (\xi_N^\dagger \tau_i \eta_{\Lambda, \Sigma}). \quad (12)$$

However, the P -wave decay calculated in perturbation theory turns out to be sensitive both to the mass splittings and to the splittings of the pion coupling constant. This sensitivity to the masses results from the diagrams in Fig. 1 giving contributions proportional to $1/(M_{\Lambda\Sigma} - M_N)$. If the Λ, Σ mass splitting is neglected but a mass difference between Λ, Σ and the nucleon is included, one finds a cancellation between the "crossed" and "uncrossed" diagrams of Fig. 1. This cancellation depends on the equality of the pion coupling constant to Λ, Σ and to the nucleon.

The observed P wave could originate from higher order pion effects or from K -meson corrections. However, there is only one source of nonvanishing terms of order $1/(M_{\Lambda, \Sigma} - M_N)$. This is the splitting of the pion coupling constants. If these terms are important then the symmetry (7), which was incorporated into \mathcal{L}_w to prevent $\Xi \rightarrow N + \pi$, is no longer valid. Σ^- decay also would be forbidden were this symmetry present, Σ^- having $Z_3 = -\frac{1}{2}$ and the nucleon $Z_3 = +\frac{1}{2}$. In the expression (12) for the S wave, then, the matrix elements for Σ^- decay vanish. Σ^- decay is allowed in the above picture of the P wave. Σ^- decay should thus be mostly P wave and show little asymmetry. There are experimental

indications that this is so.⁶ $\Xi^- \rightarrow N + \pi$, on the other hand, remains forbidden; there must be K corrections before the interaction (10) is contracted into \mathcal{L}_{eff} to allow this process.

Taking the pion coupling-constant splittings to be the entire source of the P wave, an expression for the matrix element for $\Lambda, \Sigma \rightarrow N + \pi$ results:

$$M_p = (M_{\Lambda, \Sigma} - M_N)^{-1} \xi_N^\dagger (\boldsymbol{\sigma} \cdot \mathbf{k}_\pi) (A\tau_i + B\zeta_i) \eta_{\Lambda, \Sigma}. \quad (13)$$

This formula is obtained by noting that the general charge-independent pion coupling to Λ and Σ is $\mathcal{L}_{\pi, \Lambda, \Sigma} = \bar{\psi}_{1,0} \gamma_5 (a\tau_i + b\zeta_i) \psi_{1,0} \varphi_\pi^i$. For the nucleon alone it is $\mathcal{L}_{N, \pi} = \bar{\psi}_3 \gamma_5 (c\tau_i) \psi_3 \varphi_\pi^i$.

The three parameters in (12) and (13) may be determined by fitting the total transition rates of $\Sigma^+ \rightarrow N^+ + \pi^0$, $\Sigma^+ \rightarrow N^0 + \pi^+$, and $\Sigma^- \rightarrow N + \pi^-$ (experimentally in the ratios 1:1:1).⁴ We find for Σ decay,

$$M = C \left[\tau_i + \zeta_i \frac{\boldsymbol{\sigma} \cdot \mathbf{k}}{|\mathbf{k}|} \right], \quad (14)$$

where \mathbf{k} is the pion momentum. The matrix elements for the three processes are

$$\begin{aligned} \Sigma^+ &\rightarrow N^+ + \pi^0, & M &= C[1 + \boldsymbol{\sigma} \cdot \mathbf{k}/|\mathbf{k}|]; \\ \Sigma^+ &\rightarrow N^0 + \pi^+, & M &= C[2^{\frac{1}{2}}]; \\ \Sigma^- &\rightarrow N^0 + \pi^-, & M &= C[2^{\frac{1}{2}}][\boldsymbol{\sigma} \cdot \mathbf{k}/|\mathbf{k}|]. \end{aligned} \quad (15)$$

It will be noted that since the S -wave ($N + \pi$) state here is pure $T = \frac{1}{2}$, neglecting the S -wave phase shifts has not affected the fitting of the total decay rates. The set of (15) is one of two solutions of fitting the ratios in Σ decay with $\Delta T = \frac{1}{2}$ if the Σ^- is to show no asymmetry.⁴

The expressions (12) and (13) evaluated for the Λ mass and decay energy gives, for Λ decay into $N^+ + \pi^-$,

$$M = (2)^{-\frac{1}{2}} C [1.2 - 0.9 \boldsymbol{\sigma} \cdot \mathbf{k}/|\mathbf{k}|],$$

which contains the necessary large parity violation^{6,7} and gives the decay rate ratio $\Sigma^+/\Lambda = 3$ in agreement with experiment.⁴

This last calculation is not to be taken too seriously. What might be significant here are the following two speculations:

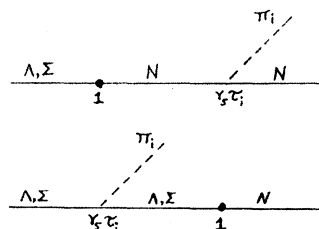
(1) Connection of the absence of $\Xi \rightarrow N + \pi$ and the lack of asymmetry in Σ^- decay, both consequences of Z_3 conservation, with the P wave in Σ^- decay resulting from a breakdown in this symmetry.

(2) Connection of the Σ branching ratio with the large parity nonconservation in Λ decay.

V. THETA DECAY

The interaction \mathcal{L}_w [Eq. (6)] contains $\Delta T = \frac{1}{2}, \frac{3}{2}$, and $\frac{5}{2}$. Depending on the value of the θ^0 branching ratio it may be necessary that significant quantities of $\Delta T = \frac{3}{2}$ and $\Delta T = \frac{5}{2}$ be present in the actual decay.⁸ If so, it

FIG. 1. Feynman diagrams for Λ and Σ decay using the interactions (11) and (16).



⁶ F. Eisler *et al.*, Phys. Rev. 108, 1353 (1957).

⁷ F. S. Crawford *et al.*, Phys. Rev. 108, 1102 (1957).

⁸ M. Gell-Mann, Nuovo cimento 5, 76 (1957).

should be pointed out that there exist ways to suppress the θ^+ rate relative to the θ^0 rate other than the $\Delta T = \frac{1}{2}$ rule.

One way is to use a K coupling which does not split the Λ and Σ masses.² The amount of θ^+ decay which does occur then would be attributed to the source of the mass splitting. However, this K interaction gives rise to selection rules contrary to fact in certain strong processes.⁹ The θ^+ selection rule follows from the symmetry in the nonsplitting K coupling,²

$$\begin{aligned} \varphi_{K^+} &\rightarrow -\varphi_{K^+}, & \varphi_{K^0} &\rightarrow \varphi_{K^0}, \\ \psi_{\frac{1}{2}} &\rightarrow i\zeta_3\psi_{\frac{1}{2}}, & \psi_{1,0} &\rightarrow i\zeta_3\psi_{1,0}, \\ \varphi_{\pi} &\rightarrow \varphi_{\pi}. \end{aligned} \quad (16)$$

This is a symmetry of \mathcal{L}_{π} so all that is required to forbid θ^+ is Z_3 conservation in the weak interaction. The θ^0 mode is allowed.

It is also possible to weakly forbid the θ^+ mode in the presence of an arbitrary K coupling. This may be done in the lowest order of the K coupling but to all orders in the pion coupling. The K coupling acts only to annihilate the initial K^+ particle. θ^+ is forbidden in this sense if that part of the weak interaction involved in θ decay has the symmetry

$$\begin{aligned} \psi_{\frac{1}{2}} &\rightarrow i\zeta_1\psi_{1,0}^{\dagger}, \\ \psi_{1,0} &\rightarrow i\zeta_1\psi_{\frac{1}{2}}^{\dagger}, \\ \varphi_{\pi} &\rightarrow -\varphi_{\pi}, \end{aligned} \quad (17)$$

in addition to the symmetry (implied by Z_3 conservation)

$$\begin{aligned} \psi_{\frac{1}{2}} &\rightarrow i\zeta_3\psi_{\frac{1}{2}}, \\ \psi_{1,0} &\rightarrow i\zeta_3\psi_{1,0}. \end{aligned} \quad (18)$$

The pion coupling is invariant under both these operations. The important point is the behavior of the K coupling. It will be shown that every term in the coupling of K^+ to the baryons, which is the only K coupling entering in lowest order, changes sign under one or the other of the operations (17) and (18). Since the final two-pion state is invariant under either operation, for each term in the transition amplitude there is a symmetry for which $K^+ \rightarrow -K^+$. θ^+ decay is thus forbidden. To prove this, consider the enumeration of the charge-raising matrices (9). The K coupling has terms of the form $\bar{\psi}_{\frac{1}{2}} \cdots M_+ \psi_{1,0} \varphi_{K^+}$ or $\psi_{1,0} \bar{M}_+ \cdots \psi_{\frac{1}{2}} \varphi_{K^+}$. The ζ_+ terms all change sign under (18). The τ_+ terms all change sign under (17).

This may be interpreted by looking at some of the intermediate processes involving nucleons (intermediate Ξ 's are included in the above). Using Gell-Mann's notation for the integral T analog of $N^0(Y^0)$ and $\Xi^0(Z^0)$, we have virtually

$$\begin{aligned} K^+ &\rightarrow N^+ + \bar{Y}^0, \\ K^+ &\rightarrow N^+ + \bar{Z}^0, \\ K^+ &\rightarrow N^0 + \bar{\Sigma}^+. \end{aligned}$$

⁹ A. Pais, Phys. Rev. **110**, 574 (1958).

The last two states on the right may not proceed into two pions because they have $Z_3=1$ and for the pions $Z_3=0$. In the first process we find that the symmetry (17) exchanges N^+ and \bar{Y}^0 with, as has been seen, negative parity. Note that the mass difference which may measure the extent to which the last symmetry breaks down is the nucleon- Σ mass difference. There is no mixing of Ξ processes with nucleon processes in the transformation (17). That is, Ξ processes are not used to cancel nucleon processes.

Upon using the interaction (10), it is seen that for a scalar K coupling, that part of \mathcal{L}_w contributing to θ decay is

$$\begin{aligned} \mathcal{L}_w^{\theta} &= \lambda [\bar{\psi}_{1,0} \gamma_{\mu} \tau_i \psi_{\frac{1}{2}} + \bar{\psi}_{\frac{1}{2}} \gamma_{\mu} \tau_i \psi_{1,0}] [\bar{\psi}_{1,0} \gamma_{\mu} \tau_i \psi_{1,0} + \bar{\psi}_{\frac{1}{2}} \gamma_{\mu} \tau_i \psi_{\frac{1}{2}}] \\ &\quad - \lambda [\bar{\psi}_{1,0} \gamma_{\mu} \gamma_5 \tau_i \psi_{\frac{1}{2}} + \bar{\psi}_{\frac{1}{2}} \gamma_{\mu} \gamma_5 \tau_i \psi_{1,0}] \\ &\quad \times [\bar{\psi}_{1,0} \gamma_{\mu} \gamma_5 \tau_i \psi_{1,0} + \bar{\psi}_{\frac{1}{2}} \gamma_{\mu} \gamma_5 \tau_i \psi_{\frac{1}{2}}], \quad i=1, 2. \end{aligned}$$

This is invariant under (17) and (18). For a pseudoscalar K coupling, invariance under (17) may be achieved by changing the signs of the $\bar{\psi}_{\frac{1}{2}} \cdots \psi_{\frac{1}{2}}$ term in (10). The interaction responsible for θ decay is then

$$\begin{aligned} \mathcal{L}_w^{\theta} &= i\lambda [\bar{\psi}_{1,0} \gamma_{\mu} \gamma_5 \tau_i \psi_{\frac{1}{2}} + \bar{\psi}_{\frac{1}{2}} \gamma_{\mu} \gamma_5 \tau_i \psi_{1,0}] \\ &\quad \times [\bar{\psi}_{1,0} \gamma_{\mu} \tau_i \psi_{1,0} - \bar{\psi}_{\frac{1}{2}} \gamma_{\mu} \tau_i \psi_{\frac{1}{2}}] \\ &\quad + i\lambda [\bar{\psi}_{1,0} \gamma_{\mu} \tau_i \psi_{\frac{1}{2}} + \bar{\psi}_{\frac{1}{2}} \gamma_{\mu} \tau_i \psi_{1,0}] \\ &\quad \times [\bar{\psi}_{1,0} \gamma_{\mu} \gamma_5 \tau_i \psi_{1,0} - \bar{\psi}_{\frac{1}{2}} \gamma_{\mu} \gamma_5 \tau_i \psi_{\frac{1}{2}}], \quad i=1, 2. \end{aligned}$$

It is hoped that that part of the K coupling involved in splitting the hyperon masses is sufficiently small to justify treating it in perturbation theory. Corrections due to a K coupling that leaves all baryon masses unsplit⁹ may be included here since they maintain the symmetries (17) and (18).

VI. τ DECAY

If the fundamental weak interaction contains much $\Delta T = \frac{5}{2}$, then one is in need of an explanation for the branching ratio in τ decay, $\tau/\tau' = 4$, characteristic of the completely symmetric $T=1$ state.¹⁰ Perhaps processes with a one-pion intermediate state dominate this mode, insuring a $T=1$ final state, and no further explanation is required. We also note that by introducing parity nonconservation into \mathcal{L}_w in a slightly different way,

$$J_{\mu}^i = \psi_{\frac{1}{2}} \gamma_{\mu} (1 + \gamma_5 \tau_3) \tau_i \psi_{\frac{1}{2}} + \text{etc.}, \quad i=1, 2$$

an interaction is obtained which for a scalar K coupling contains $\Delta T = \frac{1}{2}, \frac{3}{2}, \frac{5}{2}$ in the θ decay terms and $\Delta T = \frac{1}{2}, \frac{3}{2}$ in the τ decay terms.

ACKNOWLEDGMENT

The author is indebted to Professor J. Schwinger for enlightening discussions.

¹⁰ G. Wentzel, Phys. Rev. **101**, 1215 (1956).