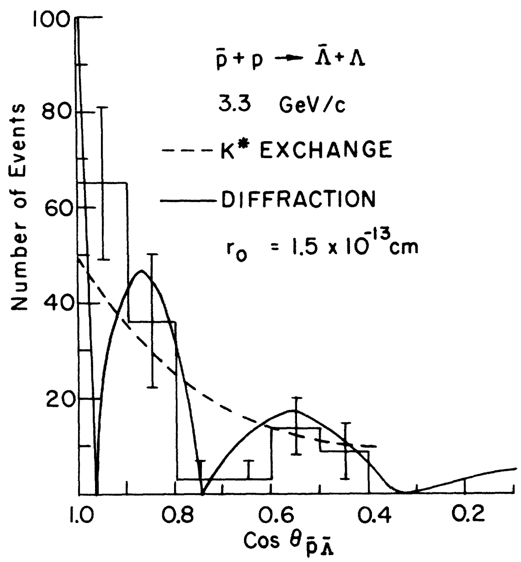

FIG. 3. Experimental results, K^* exchange, and diffraction fit for $\bar{p}+p\to\bar{\Lambda}+\Lambda$ at 3.3 GeV/c.

$\sim 1\times 10^{-13}$ cm. This fact supports the assumption of a narrow annular diffraction region. One is thus led to the conclusion that strong absorption in the entrance channel may dominate the angular distribution regardless of the details of the process. The fact that the first minimum is not as pronounced as the second one is typical also of nuclear reactions[2] and may be explained by finer details of the interaction.

The same ideas have also been applied to other quasielastic processes such as $K^+ + n \to K^0 + p$, $\pi^- + p \to n + p$, $K^+ + p \to K^* + N^*$, etc. Similar fits were obtained. The theory underlying this phenomenological approach is being investigated.

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[7]The annihilation radius is defined by $\sigma_{\rm ann} = \pi R_{\rm ann}^2$.

TRANSFORMATION PROPERTIES OF NONLEPTONIC WEAK INTERACTIONS*

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The $\Delta T = \frac{1}{2}$ rule for nonleptonic decays of strange particles means that the part of the Hamiltonian $H_{\rm W}(\Delta S = +1)$, responsible for these decays with $\Delta S = 1$, transforms like the K^0 meson with respect to the hypercharge gauge transformation and isospin rotations $[H_{\rm W} = H_{\rm W}(\Delta S = +1) + H_{\rm W}(\Delta S = -1)$; $H_{\rm W}(\Delta S = -1) = H_{\rm W}^\dagger(\Delta S = +1)]$. We would like to propose that $H_{\rm W}(\Delta S = +1)$ transforms like the K^0 meson with respect to all SU_3 transformations,[1] and $H_{\rm W}$ is approximately invariant under the product of parity conjugation (P) and R conjugation.[2] We shall discuss some consequences of these proposed rules on nonleptonic decays of strange particles.

The first part of the proposal[3] means that $H_{\rm W}(\Delta S = +1)$ is an irreducible tensor operator transforming like the operator E_3 of Behrends et al.[4] We can offer no a priori justification for this extension of the $\Delta T = \frac{1}{2}$ rule, but merely point out that assignments of irreducible tensor characters to symmetry-breaking interactions (e.g., electromagnetic,[5] mass-splitting[6]) are not unprecedented and have been fruitful. The new rule, of course, encompasses all the consequences of the $\Delta T = \frac{1}{2}$

rule.

Strictly speaking, R conjugation is a physically meaningless concept, since strong interactions do not appear to respect R invariance.[5] If the violation of R invariance is small, as dynamical calculations[7] of the ratio ($\simeq\frac{1}{3}$) of the ratio of the F-type to D-type meson-baryon couplings indicate,[8] then RP invariance of the weak Hamiltonian may nevertheless be a useful concept in the approximation in which the "small" R-violating part of strong interactions is neglected. This is the supposition we shall subscribe to. In this connection it is important to note, for the reason discussed later, that in Cabibbo's theory of leptonic decays[9] the vector currents are F type, whereas the axial vector currents are predominantly D type (the ratio being $\simeq 0.95{:}0.30$).

According to the phase convention of de Swart,[10] bases of the eight-dimensional representation transform under complex conjugation as (y = hypercharge)[11]

$$|t, t_3, y\rangle^* = (-1)^{t_3+\frac{1}{2}y}|t, -t_3, -y\rangle,$$

while under R conjugation they transform as[11]

$$R|t, t_3, y\rangle = |t, -t_3, -y\rangle.$$

Therefore if we denote a state of n bosons belonging to the (π, K) octet by $|nM\rangle$, we have

$$R|nM\rangle = (-1)^Q C|nM\rangle,$$

where C is the charge conjugation operator and Q is the total charge of the system. Since charge is conserved in nonleptonic decays, the consequences of RP invariance are the same as those of CP invariance for nonleptonic K decays. This is not the case for nonleptonic hyperon decays, however, since C transforms the baryon octet into the antibaryon octet, while R does not.

The irreducible tensor character of H_W enables us to express the amplitudes for hyperon decays as

$$\langle B'(t', t_3', y)\pi|H_W|B(t, t_3, y)\rangle = \sum_T C_{t',1}(T, t_3-\tfrac{1}{2}; t_3', t_3-\tfrac{1}{2}-t_3')C_{t,\frac{1}{2}}(T, t_3-\tfrac{1}{2}; t_3, -\tfrac{1}{2})$$

$$\times \sum_{\mu,\gamma,\gamma'} \begin{pmatrix} 8 & 8 & \mu_{\gamma'} \\ t',y' & 1,0 & T,y' \end{pmatrix} \begin{pmatrix} 8 & 8 & \mu_\gamma \\ t,y & \frac{1}{2},1 & T,y' \end{pmatrix} A(\mu_{\gamma\gamma'}),\quad y'=y+1, \tag{1}$$

where $B(t, t_3, y)$ represents the parent and $B(t', t_3', y')$ the daughter, $C_{t,t'}(T, T_3; t_3, t_3')$ is the usual SU_2 Clebsch-Gordan coefficient, and

$$\begin{pmatrix} \mu_1 & \mu_2 & \mu_\gamma \\ \nu_1 & \nu_2 & \nu \end{pmatrix},\quad \nu = (t, y),$$

is the isoscalar factor of Edmonds[12] and de Swart.[10] The summation index μ runs over dimensionalities 8, 10, 10*, and 27, and γ, γ' denote the R-conjugation parity (relevant only for $\mu = 8$). $A(\mu_{\gamma\gamma'})$ is the "reduced" matrix element. The products of isoscalar factors appearing in (1) are tabulated in Table I. There are four independent, observable nonleptonic hyperon decay processes under the $\Delta T = \frac{1}{2}$ rule:

$$\Xi \to \Lambda + \pi,$$
$$\Sigma \to N + \pi\ (T_{N\pi} = \tfrac{3}{2}),$$
$$\Sigma \to N + \pi\ (T_{N\pi} = \tfrac{1}{2}),$$
$$\Lambda \to N + \pi.$$

Table I. Numerical values of the products $\begin{pmatrix} 8 & 8 & \mu_{\gamma'} \\ t',y' & 1,0 & T,y' \end{pmatrix}\begin{pmatrix} 8 & 8 & \mu_\gamma \\ t,y & \frac{1}{2},1 & T,y+1 \end{pmatrix}$.

Processes	$8_{11} \equiv 8_d$	$8_{22} \equiv 8_f$	8_{12}	8_{21}	10	10*	27
$\Xi \to \Lambda + \pi$	$-(3/50)^{1/2}$	0	$-1/(30)^{1/2}$	0	$1/2\sqrt{6}$	$-1/2\sqrt{6}$	$(3/50)^{1/2}$
$\Sigma \to N + \pi$ ($T = \frac{3}{2}$)	0	0	0	0	$-1/2$	0	$1/2$
$\Sigma \to N + \pi$ ($T = \frac{1}{2}$)	$-9/20$	$1/4$	$3(5)^{1/2}/20$	$-3(5)^{1/2}/20$	0	$1/4$	$-1/20$
$\Lambda \to N + \pi$	$-3/20$	$-1/4$	$-3(5)^{1/2}/20$	$-(5)^{1/2}/20$	0	$1/4$	$3/20$

In Eq. (1) these are expressed in terms of seven reduced matrix amplitudes. RP invariance of the weak Hamiltonian further implies that $A(8_{12}) = A(8_{21}) = 0$, $A(10) = A(10^*)$ for the p-wave amplitudes in (1); $A(8_d) = A(8_f) = A(27) = 0$, $-A(10) = A(10^*)$ for the s-wave amplitudes. From these considerations we obtain two sum rules, which may be written as

$$(\tfrac{3}{2})^{1/2}(\Sigma_-^{\ -} - \Sigma_+^{\ +}) + \Lambda_-^{\ 0} = 2\Xi_-^{\ -} \quad \text{(for } p \text{ wave)}, \qquad (2)$$

$$(\tfrac{3}{2})^{1/2}\Sigma_-^{\ -} + 6^{-1/2}\Sigma_+^{\ +} + \Lambda_-^{\ 0} = 2\Xi_-^{\ -} \quad \text{(for } s \text{ wave)}; \qquad (3)$$

where the superscripts denote the charge of the parent, subscripts that of the decay pion.

If we assume that $\Sigma_-^{\ -}$ is purely s wave and $\Sigma_+^{\ +}$ purely p wave, and consequently $\alpha(\Sigma_0^{\ +}) \simeq 1$, then by virtue of the triangle relation

$$\Sigma_0^{\ +} = 2^{-1/2}(\Sigma_-^{\ -} - \Sigma_+^{\ +})$$

we can write Eqs. (2) and (3) as

$$\sqrt{3}\,\Sigma_0^{\ +} + \Lambda_-^{\ 0} = 2\Xi_-^{\ -}. \qquad (4)$$

We assume that Eq. (4) is to hold for the covariant amplitudes A and B, defined by

$$\langle B'\pi | H_W | B \rangle = (2\omega)^{-1/2}(m'/E')^{1/2} u_{B'}(A + \gamma_5 B) u_B, \qquad (5)$$

where ω is the c.m. energy of the decay pion, m' and E' are the mass and c.m. energy of the decay baryon. The sum rule (4) is compared with available experimental data in Fig. 1. Table II summarizes the experimental data taken for this comparison. The sum rule (4) implies that the three vectors $\sqrt{3}\,\Sigma_0^{\ +}$, $\Lambda_-^{\ 0}$, and $2\Xi_-^{\ -}$ form a triangle. This is approximately borne out in Fig. 1. The other possibility that $\Sigma_+^{\ +}$ ($\Sigma_-^{\ -}$) is pure s (p) wave in Eqs. (2) and (3) is not compatible with experiments.

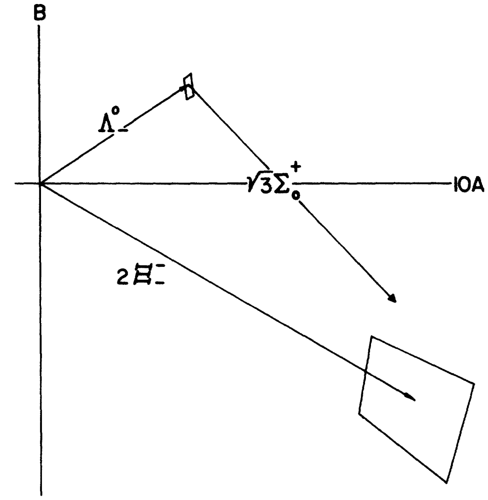

FIG. 1. Two-dimensional plot of the amplitudes $\Lambda_-^{\ 0}$, $\sqrt{3}\,\Sigma_0^{\ +}$, and $2\Xi_-^{\ -}$: These amplitudes are represented by two-dimensional vectors with components A and B. See Eq. (5). The squares represent experimental uncertainties.

Up to this point, we have not assumed any definite form of the Hamiltonian. If one assumes the weak Hamiltonian to be current × current type, fundamentally or phenomenologically, and that the currents transform as members of an octet, then the general form of the Hamiltonian responsible for nonleptonic decays, satisfying the $\Delta T = \frac{1}{2}$ rule, is

$$H_W = j_\mu^{(1,1)} S_\mu^{(1/2,1/2)\dagger} - \frac{1}{\sqrt{2}} j_\mu^{(1,0)} S_\mu^{(1/2,-1/2)\dagger} + c j_\mu^{(0,0)} S_\mu^{(1/2,-1/2)\dagger} + \text{H.c.}$$

in the notation of Behrends and Sirlin,[13] where c is an arbitrary real constant. $H_W(\Delta S = +1)$ in this case transforms like a mixture of the 8_d-

Table II. Representative experimental values for nonleptonic hyperon decays.

Process	α[a]	γ	Lifetime[b] (10^{-10} sec)	Branching ratio
$\Sigma_0^{\ +}$	+1 (assumed)		Σ^+: $0.81^{+0.06}_{-0.05}$	50%
$\Lambda_-^{\ 0}$	-0.61 ± 0.05	>0[a]	Λ^0: 2.51 ± 0.09	67%
$\Xi_-^{\ -}$	$+0.62 \pm 0.11$	<0[a]	Ξ^-: $1.28^{+0.38}_{-0.98}$	100%

[a]These are taken from F. S. Crawford, in Proceedings of the International Conference on High-Energy Nuclear Physics, Geneva, 1962 (CERN Scientific Information Service, Geneva, Switzerland, 1962), p. 827. We assume $\alpha(\Sigma_0^{\ +}) = 1$ (see text).

[b]W. H. Barkas and A. H. Rosenfeld, University of California Radiation Laboratory Report No. UCRL-8030 Rev., April 1963 (unpublished).

and 27-dimensional representations (the 10 does not contain the $Y=1$ isodoublet; the 8_f and 10^* representations are antisymmetric in two currents, therefore nonexistent). If we demand that $H_W(\Delta S=+1)$ in (9) transforms like K^0 under SU_3 transformations, the value of c must be $-1/\sqrt{6}$. In order to make the Hamiltonian (9) RP invariant, it is sufficient to demand that the current octet be RP invariant [in the sense that

$$RPj_\mu^{(t,t_3)}P^{-1}R^{-1}=j_\mu^{(t,-t_3)},$$

$$RPs_\mu^{(t,t_3)}P^{-1}R^{-1}=(-1)^{t_3+\frac{1}{2}}s_\mu^{(t,t_3)\dagger},$$

according to the phase convention of reference 13]. This requires the vector currents to be F type, and the axial-vector currents to be D type. These transformation properties are precisely those required of the currents in Cabibbo's theory of leptonic processes[9] in our approximation. It is interesting to speculate on the form of weak-interaction Hamiltonian which unifies Cabibbo's theory and the present one with intermediate vector bosons, but we shall not pursue this problem here.

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[1]See, for instance, M. Gell-Mann, Phys. Rev. 125, 1067 (1962); Y. Ne'eman, Nucl. Phys. 26, 222 (1961).

[2]M. Gell-Mann (unpublished); J. J. Sakurai, Phys. Rev. Letters 7, 426 (1962). In this paper Sakurai discusses the possibility that H_W is invariant under R. However, as S. B. Treiman has pointed out to the author (private communication), R invariance forbids the decay mode $K_1^0\to 2\pi$. Sakurai also notes the relation $\alpha(\Xi_-^-)=-\alpha(\Lambda_-^0)$. H. Ruegg called the author's attention to the fact that this relation does not follow from R invariance in general.

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[8]On the phenomenological side, the ratio $\frac{1}{3}$ gives $G_{\Lambda\pi}^2\simeq 11$ in agreement with J. J. de Swart and C. K. Iddings [Phys. Rev. 130, 312 (1963)] on the analysis of the low-energy Σ-p, Σ-d interactions. Also, if one believes the Goldberger-Treiman relation is valid for all leptonic decays, the analysis of N. Cabibbo [Phys. Rev. Letters 10, 531 (1963)] implies a similar ratio.

[9]N. Cabibbo (reference 8).

[10]J. J. de Swart (to be published).

[11]J. J. de Swart (reference 8), Eqs. (8.2), (8.3), and (17.1). Our notation $|t,t_3,y\rangle$ corresponds to de Swart's M_i $(i=1,\cdots,8)$. Identification with the boson octet is made as follows: $|\frac{1}{2},\frac{1}{2},1\rangle=K^+$, etc., except $|1,1,0\rangle=-\pi^+$ and $|\frac{1}{2},-\frac{1}{2},-1\rangle=-K^-$. This gives then $(\pi^-)^*=\pi^+$, $(K^-)^*=K^+$ to agree with the usual field theory convention of phases under charge conjugation. Under R conjugation, we have $K^+\leftrightarrow -K^-$; $\pi^+\leftrightarrow -\pi^-$; η^0,π^0 invariant; $p\leftrightarrow\Xi^-$; $n\leftrightarrow\Xi^0$; $\Sigma^+\leftrightarrow -\Sigma^-$; Σ^0,Λ^0 invariant.

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