$\to \pi^{\pm}+n$, $K^{\pm}+n \to K^{\pm}+n$, etc., which have a much higher forward cross section than the charge exchange, would be ideal.

The author wishes to express his appreciation for discussions with R. C. Arnold and B. Sakita.

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*Work performed under the auspices of the U. S. Atomic Energy Commission.

[1]S. W. Kormanyos, A. D. Krisch, J. R. O'Fallon, K. Ruddick, and L. G. Ratner, Phys. Rev. Letters 16, 709 (1966).

[2]R. M. Heinz and M. H. Ross, Phys. Rev. Letters 14, 1091 (1965).

[3]A. Yokosawa, S. Suwa, R. Hill, R. Esterling, and N. Booth, Phys. Rev. Letters 16, 714 (1966).

[4]A similar suggestion was made by S. Minami, Phys. Rev. Letters 16, 549 (1966); however, our treatment differs from that of this reference.

[5]R. W. Meier, P. Scherrer, and G. Trumpy, Helv. Phys. Acta 27, 577 (1954).

[6]G. Höhler, J. Baacke, H. Schlaile, and P. Sonderegger, Phys. Letters 20, 79 (1966).

[7]For more complete calculation see S. Suwa and A. Yokosawa, unpublished.

[8]R. Lamb, R. Lundy, T. Novey, A. Yokosawa, and D. Yovanovic, unpublished information.

[9]A crystal of LMN (24 D_2O) was used by Lushchikov et al., Dubna, 1965, and 10% of polarization was estimated.

WEAK-INTERACTION UNIVERSALITY AND OCTET DOMINANCE*

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In the Sugawara-Suzuki model[1-5] of nonleptonic hyperon decays, the s-wave amplitudes are simply proportional to the matrix elements of the weak Hamiltonian evaluated between single-baryon states (weak spurion). As pointed out by Sugawara,[1] we may actually estimate the numerical value of these amplitudes in the current-current picture by summing over a set of single-particle states inserted between the two currents.

In this note we report on our attempt at such a calculation. As input information, we use the universal weak coupling constant, Cabibbo's[6] factor $\sin\theta$, and the nucleon electromagnetic form factors. As output we obtain all the s-wave amplitudes. Despite the neglect of higher intermediate states, we find that our results are in reasonable agreement with experiment. Corresponding to the three undetermined parameters in the Sugawara-Suzuki scheme, we remark on three features of our predictions: (1) The absolute magnitudes are roughly correct. (2) Octet dominance emerges if we do not assume it initially. (3) The ratio Λ_-^0/Ξ_-^- (or alternatively, the weak spurion d/f ratio) comes out reasonably well.

Thus we find support for a current-current form for the hyperon nonleptonic decay interaction. Point (1) implies that the factor $\sin\theta$ is needed for nonleptonic as well as leptonic decay processes[7] and strengthens the conclusion[8] that it is a fundamental constant rather than a symmetry-breaking effect. The two types of processes are thus unified. Point (3) coupled with the observation[3] that the weak spurion has about the same d/f ratio as the mass-splitting spurion leads us to speculate that the Gell-Mann–Okubo[9] interaction is also of current-current form.

We start by assuming that the nonleptonic part of the universal weak current-current interaction is to be written in the symmetrized form

$$H_W^{\rm NL} = (G/\sqrt{2})\cos\theta\,\sin\theta\tfrac{1}{2}\{[(V_2^{\ 1}+P_2^{\ 1})_\mu, (V_1^{\ 3}+P_1^{\ 3})_\mu]_+ + (2 \leftrightarrow 3)\}, \tag{1}$$

where $G=10^{-5}/M^2$, $\theta \simeq 0.26$; and $V_b^{\ a}$ and $P_b^{\ a}$ are, respectively, the vector and pseudovector current octets. We shall also investigate the possibility that $H_W^{\rm NL}$ is given by the pure octet:

$$H_W^{\rm NL'} = (G/\sqrt{2})\cos\theta\,\sin\theta\tfrac{1}{2}\{[(V_c^{\ 2}+P_c^{\ 2})_\mu, (V_3^{\ c}+P_3^{\ c})_\mu]_+ + (2 \leftrightarrow 3)\}. \tag{1'}$$

Using Eq. (1) and the partially-conserved-axial-vector-current (PCAC) hypothesis,[10] we obtain a conveniently normalized[11] s-wave amplitude A, for emission of a pion, $\pi_b{}^a$:

$$A=(2Mi/g_{\pi NN})(2k_0)^{1/2}\langle N'\pi_b{}^a(k)|H_W{}^{\rm NL}(s\text{ wave})|N\rangle$$
$$=(1/2g_A)G\sin\theta\cos\theta\langle N'|\{\delta_1{}^a([V_2{}^1,V_b{}^3]_+ +[P_2{}^1,P_b{}^3]_+ +[2\leftrightarrow 3])-\delta_b{}'([V_2{}^a,V_1{}^3]_+ +[P_2{}^a,P_1{}^3]_+ +[2\leftrightarrow 3])$$
$$+\delta_2{}^a([V_b{}^1,V_1{}^3]_+ +[P_b{}^1,P_1{}^3]_+)-\delta_b{}^2([V_3{}^1,V_1{}^a]_+ +[P_2{}^1,P_1{}^a]_+)\}|N\rangle, \tag{2}$$

where M is the nucleon mass, $g_A\simeq 1.18$, $(g^2{}_{\pi NN}/4\pi)=14.6$, and we have suppressed the Lorentz index for simplicity. By CP invariance[2] only the parity-conserving spurion contributes on the right-hand side of Eq. (2) as indicated. A similar equation holds when we use Eq. (1′) instead of Eq. (1).

Our procedure is to approximate Eq. (2) by summing over a set of intermediate octet baryon states. We need the vector and axial-vector form factors, defined by

$$\langle N'(p')|V_{b\mu}{}^a(0)|N(p)\rangle=-iM(p_0p_0{}')^{-1/2}\bar u(p')\Big\{\gamma_\mu\{[F_1{}^p(q^2)+\tfrac12F_1{}^n(q^2)]F_b{}^a-\tfrac32F_1{}^n(q^2)D_b{}^a\}$$
$$+(\sigma_{\mu\nu}q_\nu/2M)\{[F_2{}^p(q^2)+\tfrac12F_2{}^n(q^2)]F_b{}^a-\tfrac32F_2{}^n(q^2)D_b{}^a\}\Big\}u(p), \tag{3a}$$

$$\langle N'(p')|P_{b\mu}{}^a(0)|N(p)\rangle=-iM(p_0p_0{}')^{-1/2}\bar u(p')\{\gamma_\mu\gamma_5[f(q^2)F_b{}^a+d(q^2)D_b{}^a]$$
$$+i(q_\mu/2M)\gamma_5[f'(q^2)F_b{}^a+d'(q^2)D_b{}^a]\}u(p), \tag{3b}$$

where $q=p-p'=(\vec q, iq_0)$, $\sigma_{\mu\nu}=-\frac12 i(\gamma_\mu\gamma_\nu-\gamma_\nu\gamma_\mu)$, and $D_b{}^a$ and $F_b{}^a$ are, respectively, the symmetric and antisymmetric SU(3) matrices. We have assumed SU(3) invariance so that all the vector form factors are given in terms of the known nucleon form factors. We use the following[12] empirical fit to the nucleon form factors:

$$F_1{}^{p,n}(q^2)=(1+q^2/4M^2)^{-1}[G_E{}^{p,n}(q^2)+(q^2/4M^2)G_M{}^{p,n}(q^2)], \tag{4a}$$

$$F_2{}^{p,n}(q^2)=(1+q^2/4M^2)^{-1}[G_M{}^{p,n}(q^2)-G_E{}^{p,n}(q^2)], \tag{4b}$$

with

$$G_E(q^2)=G_M{}^p(q^2)/\mu_p=G_M{}^n(q^2)/\mu_n=(1+q^2/0.71)^{-2},\quad q\text{ in BeV}/c, \tag{5a}$$

$$G_E{}^n(q^2)=0, \tag{5b}$$

and $\mu_p\simeq 2.79$, $\mu_n\simeq -1.91$.

We may relate the two axial-vector form factors to each other by using Nambu's form[13] of the PCAC hypothesis. This gives

$$d'(q^2)=[4M^2/(q^2+M_\pi{}^2)]d(q^2), \tag{6a}$$

$$f'(q^2)=[4M^2/(q^2+M_\pi{}^2)]f(q^2). \tag{6b}$$

Actually in Eqs. (6) we must replace $M_\pi{}^2$ by $M_K{}^2$ when the relevant current is strangeness-changing, but this turns out to have negligible effects for our purposes. Finally, we relate $d(q^2)$ and $f(q^2)$ to the nucleon electromagnetic form factors by using chiral SU(3)⊗SU(3) symmetry.[14] With the baryons in the $((\underline{6},\underline{3}),(\underline{3},\underline{6}))$ representation we obtain, as pointed out by Hara,[15] the characteristic SU(6) results and in addition

$$d(q^2) = \tfrac{3}{5}g_A[F_1^P(q^2) + \tfrac{3}{2}F_1^n(q^2)], \quad (7a)$$

$$f(q^2) = \tfrac{3}{5}g_A[\tfrac{2}{3}F_1^P(q^2) - \tfrac{1}{2}F_1^n(q^2)], \quad (7b)$$

where we have normalized the result to obtain

$$d(0) + f(0) = 1.18.$$

Collecting together Eqs. (3)-(7) and substituting into Eq. (2) gives, after some manipulations, our final result for the s-wave amplitudes:

$$A = \frac{1}{g_A} G \sin\theta \cos\theta \frac{M^3}{(2\pi)^2}[I_V + I_P], \quad (8)$$

$$I_V = \int_1^\infty \frac{dx(x^2-1)^{1/2}}{[1+(2M^2/0.71)(x-1)]^4}\{S_1 + S_2(x-1)\} = (0.0778)S_1 + (0.0392)S_2, \quad (8a)$$

$$I_P = \int_1^\infty \frac{dx(x^2-1)^{1/2}}{[1+(2M^2/0.71)(x-1)]^4} \frac{1}{(x+1)^2}\left\{(x+2) - \frac{(x-1)(x-1+M_\pi^2/2M^2+M_K^2/2M^2)}{(x-1+M_\pi^2/2M^2)(x-1+M_K^2/2M^2)}\right\}\{R_1 + R_2(x-1) + R_3(x-1)^2\}$$

$$= (0.0341)R_1 + (0.0114)R_2 + (0.0155)R_3, \quad (8b)$$

where the R's and S's are given for the Λ_-^0, Ξ_-^-, and Σ_+^+ decays in Table I. [The other decays may be obtained from these by using the Λ and Ξ $\Delta I = \frac{1}{2}$ rules and the Sugawara-Suzuki relations[1,2]: $A(\Sigma_-^-) + \sqrt{2}A(\Sigma_0^+) = -A(\Sigma_+^+)$ and $A(\Lambda_-^0) + 2A(\Xi_-^-) = -(3/\sqrt{6})A(\Sigma_-^-)$ which hold in our model.] In deriving Eq. (8) we assumed that the inital and final baryons were at rest and that all baryon masses were degenerate at the nucleon mass. The integrals appearing were evaluated numerically.[16] I_V is the part of the contribution from the vector currents and I_P is the part from the pseudovector currents. In Table I we have also listed the coefficients which would be obtained had we used Eq. (1′) instead of Eq. (1).

The results of the calculation and comparison with experiment[11] are given in Table II. In view of the approximations we have made, the general agreement is very striking. This would appear to indicate that the universal current-current picture of weak interactions has been successfully extended to nonleptonic hyperon decays. To some extent it also makes our approximations plausible.

We note that if we had not used Cabibbo's factor our predicted results would be about four times those listed. This seems to be evidence that $\sin\theta$ is indeed required for these nonleptonic decays.

It is remarkable that $A(\Sigma_+^+)$ comes out to be very small. The contribution to this amplitude comes[1] only from the $\{27\}$ spurion and hence vanishes in the limit of complete octet dominance. It can easily be seen from Eq. (8) and Table I that the reason for its low value is an approximate cancellation between I_V and I_P. Presumably a better estimate of the axial-vector form factors (which contribute only to I_P) would lead to more exact cancellation. Thus an argument has been presented in favor of octet dominance arising as a dynamical effect without the introduction of neutral currents

Table I. Coefficients in Eqs. (8). (For simplicity, we have set $\mu_n = -\frac{2}{3}\mu_p$.) The factor X is $(5/3g_A)^2$.

	No octet dominance [Eq. (1)]					Octet dominance [Eq. (1′)]				
Decay	R_1X	R_2X	R_3X	S_1	S_2	R_1X	R_2X	R_3X	S_1	S_2
$6^{1/2}\Lambda_-^0$	52/3	$20\mu_p$	$3\mu_p^2$	−3	$13\mu_p^2/3$	28	$28\mu_p$	$3\mu_p^2$	−3	$7\mu_p^2$
$6^{1/2}\Xi_-^-$	−44/3	$-4\mu_p$	$3\mu_p^2$	−3	$-11\mu_p^2/3$	−68/3	$-12\mu_p$	$3\mu_p^2$	−3	$-19\mu_p^2$
Σ_+^+	8/9	$(16/3)\mu_p$	$2\mu_p^2$	−2	$2\mu_p^2/9$	0	0	0	0	0

Table II. Results of calculation. All numbers are to be multiplied by $10^{-7} M_\pi$.

Amplitude	Experiment[a]	Prediction	Prediction assuming Eq. (1′) instead of (1)
$A(\Lambda_-{}^0)$	3.3	2.9	4.6
$A(\Xi_-{}^-)$	−4.4	−2.4	−4.4
$A(\Sigma_+{}^+)$	−0.1	0.4	0[b]

[a]See Ref. 11.
[b]Implicitly assumed.

[as in Eq. (1′)]. This would lead us to prefer the universal form of H_W given by Eq. (1).

To improve this calculation one might take careful account of mass differences among the baryons and contributions from higher intermediate states. Further developments will be given elsewhere.

We wish to thank Professor Y. Nambu for helpful encouragement and discussions and the members of the high-energy group at Chicago for stimulating conversations.

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*This work supported in part by the U. S. Atomic Energy Commission.

[1]H. Sugawara, Phys. Rev. Letters 15, 870, 997 (1965).

[2]M. Suzuki, Phys. Rev. Letters 15, 986 (1965).

[3]Y. Hara, Y. Nambu, and J. Schechter, Phys. Rev. Letters 16, 380 (1966).

[4]S. Badier and C. Bouchiat, to be published.

[5]L. S. Brown and C. M. Sommerfield, Phys. Rev. Letters 16, 751 (1966).

[6]N. Cabibbo, Phys. Rev. Letters 10, 531 (1963).

[7]This question has been raised by R. E. Marshak, "Present Status of Weak Interactions" (unpublished).

[8]L. K. Pandit and J. Schechter, Phys. Letters 19, 56 (1965); D. Amati, C. Bouchiat, and J. Nuyts, Phys. Letters 19, 59 (1965); A. Sato and S. Saski, to be published; C. A. Levinson and I. J. Muzinich, Phys. Rev. Letters 15, 715 (1965); R. Oehme, Phys. Rev. Letters 16, 215 (1966).

[9]M. Gell-Mann, Phys. Rev. 125, 1067 (1962); S. Okubo, Progr. Theoret. Phys. (Kyoto) 27, 949 (1962).

[10]M. Gell-Mann and M. Lévy, Nuovo Cimento 16, 705 (1960); Y. Nambu, Phys. Rev. Letters 4, 380 (1960).

[11]This is to be compared with the experimental values given in Table II of Ref. 3.

[12]L. Chan, K. Chen, J. Dunning, Jr., N. Ramsey, J. Walker, and R. Wilson, Phys. Rev. 141, 1298 (1966).

[13]Nambu, Ref. 9.

[14]M. Gell-Mann, Physics 1, 63 (1964); P. Freund and Y. Nambu, Ann. Phys. (N. Y.) 32, 201 (1965); R. Marshak, N. Mukunda, and S. Okubo, Phys. Rev. 137, B698 (1965).

[15]Y. Hara, Phys. Rev. 139, B134 (1965). Details of calculation are given in J. Schechter and Y. Ueda, Phys. Rev. 144, 1338 (1966).

[16]We note that these integrals converge rapidly and that our results are not critically dependent on the contributions to the nucleon form factors from the range of momentum transfer above where Eq. (5a) is valid. See Ref. 12. Furthermore, our results are not essentially changed if the degenerate mass M in Eq. (8) is increased from M to $\frac{1}{2}(M_N+M_\Sigma)$. However, $M=\frac{1}{2}(M_\Lambda+M_\Xi)$ gives results which are too small but in the same ratio. On the other hand, the use of such a high value is probably implausible in the approximation where all baryons are degenerate and the form factors are only known for the nucleons.

OBSERVATION OF AN ENHANCEMENT IN THE $I=0$ $K_1{}^0K_1{}^0$ SYSTEM AT 1068 MeV*

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We report the observation of an enhancement in the $K_1{}^0K_1{}^0$ spectrum with strangeness zero, isospin zero, even parity, and even charge conjugation, which we refer to as the S^*. The mass of the S^* is 1068 ± 10 MeV with a width of 80 ± 15 MeV. Our analysis favors a zero spin for the S^*. The cross section for S^* production with both $K_1{}^0$ decays observed in the reaction

$$\pi^- + p \to n + S^*, \quad S^* \to K_1{}^0K_1{}^0$$

is approximately 1.5 μb at 6 GeV/c.

The differences between the S^* and the previously reported $K_1{}^0K_1{}^0$ threshold effect in lower energy experiments[1] will be discussed below.

The data were obtained from exposures of the Brookhaven National Laboratory 80-inch liquid-hydrogen bubble chamber to 6-GeV/c π^+ and π^- mesons. We have film equivalent to approximately 4 events per μb for π^+ and 18 events per μb for π^-. The final states rele-