Universality, $SU(3)$ Symmetry, and Total Cross-Section Relations*

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Total cross-section relations derivable on the basis of $SU(3)$ symmetry and vector-meson universality are examined for their sensitivity to small deviations from exact symmetry and from universality. A discussion is given on the additional information provided by the analysis of the charge-exchange and hypercharge-exchange reactions in meson-baryon scattering. It is pointed out that the relations of Levinson *et al.* are not sensitive to the departures from universality. According to the present high-energy data, it is found that while $SU(3)$-symmetric couplings are good to about 10%, the universality hypothesis still remains to be tested. Some tests are indicated which afford a check on the mechanism of $SU(3)$ breaking that is assumed in the analysis.

1. INTRODUCTION

THE hypothesis that vector-meson fields are coupled universally to certain hadronic currents was originally proposed by Sakurai.[1] In the case of massive vector mesons, one naturally studies this hypothesis as applied to the vertex functions evaluated at zero four-momentum transfer ($t=0$). Correspondingly, in Regge-pole models involving vector-meson exchanges, the universality hypothesis may be invoked for the factorized Regge residues at $t=0$. The universality hypothesis when coupled with $SU(3)$ symmetry admits the derivation of well-known linear relations between elastic scattering amplitudes (assuming the dominance of peripheral t-channel exchanges) and thus between the corresponding total cross sections. Some of these total cross-section relations have agreed very well with the high-energy experimental data, while others have exhibited sizable deviations outside the experimental uncertainties.[2] Although these deviations in themselves are not surprising because of the approximate nature of the $SU(3)$ symmetry and universality hypotheses, it is not clear why some relations deduced on the same basis should fare better than others. On the other hand, it should be realized that good or bad agreement of a given cross-section relation with experiment may not have a direct bearing on the validity of universality inasmuch as there are, in general, small effects such as $SU(3)$ breaking or deviations from the nonet hypothesis, as well as several different ways in which universality may fail, and all these effects have to be considered simultaneously. Furthermore, it is necessary to examine critically the sensitivity of the cross-section relations to various departures from the simplified theory. For these reasons one should explicitly include parameters describing the small effects, which are usually neglected in deriving the cross-section relations to be compared with experiments. By such an analysis of the data one can make realistic estimates on the validity of universality or $SU(3)$ symmetry as applied to high-energy scattering amplitudes.

In Sec. 2 we examine the experimental status of the total cross-section relations, by taking into account parameters which describe the deviations. In Sec. 3 we discuss what additional information can be obtained by investigating the charge-exchange and hypercharge-exchange reactions in meson-baryon scattering. Section 4 is devoted to some comments and a summary of our approach.

2. ANALYSIS OF TOTAL CROSS-SECTION RELATIONS

It is well known[3] that the physical ω and ϕ states are to be regarded as linear combinations of $SU(3)$-symmetric states denoted by ω_1 and ω_8:

$$\phi=\cos\theta\,\omega_8-\sin\theta\,\omega_1\,,$$
$$\omega=\sin\theta\,\omega_8+\cos\theta\,\omega_1\,,$$

where θ is known as the ω-ϕ mixing angle. The canonical value of θ_0 for the mixing angle according to the nonet hypothesis[4] is

$$\cos\theta_0=\sqrt{\tfrac{2}{3}}\,. \quad (1)$$

Predictions of ω and ϕ decay rates based on Eq. (1) are in rough agreement with the experiment. Nevertheless, one must allow for possible deviations from the value as given by Eq. (1) when dealing with the exchanges of ω and ϕ in scattering processes ($t\lesssim 0$ for scattering processes, whereas $t=m_V^2$ for decay rates). To this end, we will write

$$\theta=\theta_0+\epsilon \quad (|\epsilon/\theta_0|\ll 1) \quad (2)$$

and regard ϵ as a small deviation from the canonical value θ_0 defined by Eq. (1).

The experimental facts[5] that (a) the reaction $\pi^-p\to\phi n$ is barely detectable in comparison to the corresponding

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[1] J. J. Sakurai, Ann. Phys. (N. Y.) **11**, 1 (1960).
[2] An experimental evaluation of various cross-section relations has been recently given by V. Barger and L. Durand, III, Phys. Rev. **156**, 1525 (1967).
[3] J. J. Sakurai, Phys. Rev. Letters **9**, 472 (1962); R. F. Dashen and D. H. Sharp, Phys. Rev. **133**, B1585 (1964).
[4] S. Okubo, Phys. Letters **5**, 165 (1963).
[5] J. H. Boyd *et al.*, Phys. Rev. **166**, 1458 (1968); J. Badier *et al.* in *Proceedings of the Twelfth Annual Conference on High-Energy Physics, Dubna, 1964* (Atomizdat, Moscow, 1965).

reaction $\pi^- p \to \omega n$, and (b) the reaction $K^- p \to \Lambda\phi$ shows a marked absence of a backward peak in contrast to the reaction $K^- p \to \Lambda\omega$, suggest that the *physical* coupling of ϕ to the nucleons is small[6]:

$$g \equiv g_{NN\phi} \simeq 0. \tag{3}$$

In the spirit of our approach, we shall treat g as a parameter, which is small compared to $g_{NN\omega}$, in writing the necessary relations among scattering amplitudes.

To proceed further, we will write the $SU(3)$-invariant vertices for the factorized vector-meson Regge-pole residues at $t=0$ in the form

$$L_0 = 2(\gamma_d d_{ijk} - i\gamma_f f_{ijk})\bar{B}_i B_j V_k - 2i\gamma_m f_{ijk} P_i^\dagger P_j V_k + (\sqrt{6}) h\omega_1 \bar{B}_i B_i. \tag{4}$$

Here, we have suppressed the dependence on space indices for convenience; the operators γ_μ and ∂_μ etc. are to be inserted at the proper places. The subscripts i, j, and k are the $SU(3)$ indices which take on values from 1 to 8. The symbols B_i, V_i, and P_i represent the baryon, vector meson, and pseudoscalar meson octets, respectively. The numerical factors and the definition of h are so chosen that the expression (4) would correspond to the one used in earlier work.[7,8] In the framework of $SU(3)$ symmetry, one naturally extends the Sakurai universality of vector-meson couplings to imply pure-f couplings to baryons in addition to the relation $\gamma_f = \gamma_m$. Consequently, deviations from exact universality can be considered by simply writing

$$\gamma_f = \gamma_m(1+u), \tag{5}$$

$$\alpha \equiv \gamma_d/\gamma_f, \tag{6}$$

where u and α are to be treated as parameters which are small compared to unity.

To account for the effects due to octet-type broken symmetry on the vertices, under the assumption that universality is nearly exact, we shall consider the following expression to be added to L_0 defined in Eq. (4):

$$L' = -2\sqrt{3}x\gamma_m(P_i^\dagger P_j + \bar{B}_i B_j) i f_{ijk} d_{k8m} V_m, \tag{7}$$

where x is a measure of the breaking of $SU(3)$ symmetry and is assumed to be small. Since the main departures from universality are already parametrized [Eqs. (5) and (6)], we do not consider different breaking strengths for baryon vertices and pseudoscalar-meson vertices (this would mean considering second-order effects, which are neglected in our analysis). Further, as will be seen later, our choice of L' does not affect the Barger-Rubin relation which is very well satisfied by experiment.

[6] H. Sugawara and F. Von Hippel, Phys. Rev. **145**, 1331 (1966).
[7] V. Barger and M. Olsson, Phys. Rev. **146**, 1080 (1966); V. Barger, M. Olsson, and K. V. L. Sarma, Phys. Rev. **147**, 1115 (1966).
[8] The parameter β used in Ref. 7 is related to the h by the expression $h - \frac{2}{3}\gamma_d = \beta\gamma_{NV}$.

Our purpose now is to incorporate the five parameters u, α, x, g, and ϵ in constructing the differences of total cross sections

$$\Delta(AB) = \sigma_t(\bar{A}B) - \sigma_t(AB). \tag{8}$$

In the framework of the Regge-pole model, which we shall use, the Δ's isolate[7] the contributions of Regge exchanges corresponding to the mesons with $J^P = 1^-$ and $C = -$ (i.e., ρ, ω, and ϕ). For this reason we shall focus our attention only on relations involving Δ's in order to examine the hypothesis of vector-meson universality. The following expressions can be easily worked out by neglecting terms of second and higher order in the small parameters:

$$\Delta(\pi^+ p) = 4\gamma_m^2(1+u+\alpha+2x)R_\rho, \tag{9}$$

$$\Delta(K^+ p) = \tfrac{1}{2}\Delta(\pi^+ p) + 2\gamma_m^2(3+3u-\alpha-6x-\sqrt{2}g/\gamma_m)R_\omega + 2\gamma_m^2(\sqrt{2}g/\gamma_m)R_\phi, \tag{10}$$

$$\Delta(K^+ n) = \Delta(K^+ p) - \Delta(\pi^+ p), \tag{11}$$

$$\Delta(pp) = 2\gamma_m^2[(1+2u+2\alpha+2x)R_\rho + (9+18u-6\alpha-18x-6\sqrt{2}g/\gamma_m - 18\sqrt{2}\epsilon)R_\omega], \tag{12}$$

$$\Delta(pn) = \Delta(pp) - 4\gamma_m^2(1+2u+2\alpha+2x)R_\rho, \tag{13}$$

where

$$g = g_\phi^0 - \sqrt{2}x\gamma_m, \tag{14}$$

$$g_\phi^0 = \frac{3\gamma_f - \gamma_d}{\sqrt{3}}\cos\theta - (\sqrt{6})h\sin\theta, \tag{15}$$

and R_ρ, R_ω and R_ϕ contain the Regge energy dependence and kinematical factors (see, e.g., Ref. 7). The parameter g (g_ϕ^0) is the coupling of the $\phi\bar{N}N$ vertex after (before) $SU(3)$ breaking is turned on.

The following two relations can be derived by neglecting the differences in the masses of the projectiles at a given laboratory momentum ($\gtrsim 6$ GeV/c):

$$\Delta(\pi^+ p) + \Delta(K^+ n) - [\Delta(K^+ p)] = 0, \tag{16}$$

$$\Delta(\pi^+ p) + \Delta(pn) - [\Delta(pp)] = -4\gamma_m^2(u+\alpha)R_\rho. \tag{17}$$

The relation (16), which is known as the Barger-Rubin relation,[9] is unaffected by the first-order deviations from the universality or $SU(3)$ symmetry which we considered in constructing L'. As we shall see later, the relation (16) is in excellent agreement with experiment and this fact may in turn be taken as an additional justification for using L' as given in Eq. (7). The second ρ-universality relation[10] (17) affords a clean test of the universality hypothesis because the symmetry-breaking parameter x does not enter the right side of Eq. (17). It should be pointed out, however, that among the five Δ's [$\Delta(\pi^+ n)$ need not be considered since it is equal to

[9] V. Barger and M. Rubin, Phys. Rev. **140**, B1365 (1965).
[10] P. G. O. Freund, in *Tokyo Summer Lectures in Theoretical Physics, 1967* (W. A. Benjamin, New York, 1968), p. 1; V. Barger, in Proceedings of the CERN Topical Conference on High-Energy Collisions of Hadrons, 1968 (unpublished).

$-\Delta(\pi^+p)$ by $SU(2)$ symmetry] there can be *only four linear relations which are independent.* One of them is the Barger-Rubin relation which does not depend on any of the parameters. Thus, in principle, only three of the five parameters could be determined separately.

To derive the remaining relations, we have to make the simplifying assumption that the Regge-trajectory intercepts of ρ, ω, and ϕ are equal, so that

$$R\equiv R_\rho \simeq R_\omega \simeq R_\phi . \quad (18)$$

In view of the near-equality of the physical masses of ρ and ω, the equality of their trajectory intercepts appears reasonable. In general, Regge-pole analyses which assume $\alpha_\rho(0)\neq\alpha_\omega(0)$ seem to determine a sizable d coupling. We feel that present data are not adequate for determining $\alpha_\rho(0)-\alpha_\omega(0)$, and that if one starts with $\alpha_\rho(0)\approx\alpha_\omega(0)$ one could obtain couplings which are almost pure f type. On the other hand, the equality between $\alpha_\phi(0)$ and $\alpha_\rho(0)$ may not appear to be a valid assumption. However, the contributions to the Δ's from ϕ exchange, fortunately, are all very small [see Eq. (3)] so that the difference between R_ω and R_ϕ contributes only to second-order terms. In any case, we may look upon the g to be determined as some average value over the energy range of interest. Using the approximation (18), we obtain

$$\Delta(\pi^+p)=4\gamma_m^2R[1+u-x+(\alpha+3x)], \quad (19)$$

$$\tfrac{1}{2}\Delta(K^+p)=4\gamma_m^2R(1+u-x), \quad (20)$$

$$\Delta(K^+n)=4\gamma_m^2R[1+u-x-(\alpha+3x)], \quad (21)$$

$$\Delta(pp)=4\gamma_m^2R(5+10u-8x-2\alpha-G), \quad (22)$$

$$\Delta(pn)=4\gamma_m^2R(4+8u-10x-4\alpha-G), \quad (23)$$

where

$$G\equiv 3\sqrt{2}g/\gamma_m+9\sqrt{2}\epsilon . \quad (24)$$

The Johnson-Treiman (JT) relations[11] $\Delta(K^+n)=\Delta(\pi^+p)=\Delta(K^+p)/2$ follow from Eqs. (19)–(21) by setting $\alpha=x=0$. However, the important point emerging from the structure of our expressions is that, in order that the JT relations be valid, $|\alpha+3x|$ should be small compared to unity. Thus an experimental evaluation of the two JT relations, which will be combined into one relation as

$$\Delta(\pi^+p)-[\lambda\Delta(K^+n)+\tfrac{1}{2}(1-\lambda)\Delta(K^+p)]=0$$
$$(\lambda \text{ is an arbitrary weighting parameter}), \quad (25)$$

should allow us to determine the parameter combination $(\alpha+3x)$.

In addition to (17), the following relations which connect the meson-baryon cross sections to the baryon-baryon cross sections, are derivable (by setting all the small parameters equal to zero):

$$\Delta(pp)=3\Delta(K^+p)-\Delta(\pi^+p), \quad (26)$$

$$\Delta(pp)=2\Delta(K^+p)+\Delta(K^+n), \quad (27)$$

$$\Delta(pp)+\Delta(pn)=3\Delta(K^+p)+3\Delta(K^+n), \quad (28)$$

$$\Delta(pp)=5\Delta(\pi^+p), \quad (29)$$

$$\Delta(pn)=4\Delta(\pi^+p). \quad (30)$$

The relations (26) and (27) are equivalent by virtue of the Barger-Rubin relation. The two relations (27) and (28) were derived originally by Levinson, Wall, and Lipkin[12] (LWL) on the basis of the quark model. These LWL relations are known to be in good agreement with the experimental data [for testing (28) use has been made of the data on deuteron targets]. Relations (29) and (30), which are known as Freund[13] relations, seem to agree poorly with the data.

As mentioned earlier, there can be only four independent cross-section relations, and therefore among the relations (26)–(30) only one (or any one linear combination of them) needs to be chosen together with the three relations (16), (17), and (25). The four relations so chosen would exhaust the information that can be obtained on the parameters in our analysis. In view of its good agreement with experiment, we can choose the LWL relation (27) or its equivalent (26). The relation (26) has the virtue that it does not depend on the neutron-target data which have, in general, large errors. More generally, it is advantageous to consider a linear combination of (26) and (27):

$$\Delta(pp)=\mu[3\Delta(K^+p)-\Delta(\pi^+p)] + (1-\mu)[2\Delta(K^+p)+\Delta(K^+n)], \quad (31)$$

where μ is a weighting parameter to be so chosen at each energy that the error on the right side of (31) will be as small as possible.

Comparison with Experiment

For the experimental comparison of the two universality relations (16) and (17) which are of the form $A-B=0$ [B is chosen to be the quantity given in the square brackets in Eqs. (16) and (17)], we define the deviation z by the formula[14]

$$z=[A-B\pm(dA^2+dB^2)^{1/2}]/(A+B). \quad (32)$$

By calculating the deviation z at various energies, we shall finally compute the average deviation $\langle z\rangle$ by appropriately weighting each z by its error. The results of comparing the two relations (16) and (17) with the

[11] K. Johnson and S. B. Treiman, Phys. Rev. Letters **14**, 189 (1965); see also R. F. Sawyer, *ibid.* **14**, 471 (1965).

[12] C. A. Levinson, N. S. Wall, and H. J. Lipkin, Phys. Rev. Letters **17**, 1122 (1966).

[13] P. G. O. Freund, Phys. Rev. Letters **15**, 929 (1965); **16**, 291 (1966).

[14] In each case we have grouped the Δ's into A and B in such a way that the denominator in Eq. (32) becomes large.

TABLE I. Comparison of the ρ-universality relations (16) and (17) with the experimental data. The deviation z is defined by Eq. (32) in the text.

Beam momentum (GeV/c)	z for relation (16)	z for relation (17)
6	-0.02 ± 0.05	0.01 ± 0.12
8	-0.21 ± 0.06[a]	0.04 ± 0.13
10	-0.02 ± 0.06	...
12	0.01 ± 0.07	0.11 ± 0.15
14	0.03 ± 0.07	0.23 ± 0.14
16	0.03 ± 0.09	0.17 ± 0.17
18	0.04 ± 0.17	-0.14 ± 0.50
	$\langle z\rangle=0.00\pm0.03$	$\langle z\rangle=0.10\pm0.06$

[a] This value is not considered in computing $\langle z\rangle$ (see text).

available data[15] are given in Table I. The data at 8-GeV/c on $\sigma_t(K^-p)$ and $\sigma_t(K^-n)$ do not seem to be generally consistent with the data at the rest of the energies. For this reason we have omitted the 8-GeV/c point in computing $\langle z\rangle$ whenever $\Delta(K^+p)$ or $\Delta(K^+n)$ are involved. The results of Table I show that the Barger-Rubin relation (16) is in good agreement with experiment. From the relation (17) and the results of Table I, we conclude that

$$-\tfrac{1}{10}(u+\alpha)=0.10\pm0.06\,. \qquad (33)$$

It should be emphasized that the value quoted in (33) is mainly the result of the measurement of $\sigma_t(np)$ at 14.0 GeV/c by Kreisler *et al.*[15] Although the right-hand side of the Eq. (33) is consistent with zero, it should be realized that due to the factor $\frac{1}{10}$ appearing in the left side of Eq. (33) departures from universality as large as 100% are not ruled out either.

A similar procedure is adopted for analyzing the cross-section relation (31), which may be rewritten as

$$\Delta(pp)-[(2+\mu)\Delta(K^+p)-\mu\Delta(\pi^+p)+(1-\mu)\Delta(K^+n)]=0\,. \qquad (31')$$

For computing the deviation z according to the formula (32), the B is chosen to represent the expression in the square brackets of (31′). By comparing the relation (31′) with experiment (see Table II) we have determined[16] the following combination of parameters:

$$\tfrac{1}{10}(5u-\alpha-G)=0.01\pm0.02\,. \qquad (34)$$

A comment on the ω-universality relation for deuteron targets is in order. The LWL relation here is $\Delta(pd)-[3\Delta(K^+d)]=0$, and the corresponding deviation z is a measure of the quantity

$$\tfrac{1}{9}(\tfrac{9}{2}u-\tfrac{3}{2}\alpha-G)\,,$$

which is not very different from the one on the left side of Eq. (34). Thus both LWL relations test for the smallness of essentially the same combination of parameters. Moreover, the success of these relations does not reflect exclusively on the validity of the universality hypothesis, since they are not only sensitive to the departures from universality, but also depend on the combination of parameters denoted by G.

None of the three relations so far discussed are affected by the departures from exact $SU(3)$ symmetry up to first order in x. As emphasized earlier, a test of the Johnson-Treiman relations is indeed a test on the smallness of the parameter-combination ζ,

$$\zeta\equiv\alpha+3x\,, \qquad (35)$$

in terms of which

$$\Delta(\pi^+p)=N(1+\zeta)\,,\quad \tfrac{1}{2}\Delta(K^+p)=N\,,\quad \Delta(K^+n)=N(1-\zeta)\,, \qquad (36)$$

where N is defined by Eq. (20). The results of our analysis of the general relation (25) are presented in Table II along with the values of λ.[17] The value of ζ emerging from the analysis is

$$\zeta=-0.25\pm0.03\,. \qquad (37)$$

3. CHARGE- AND HYPERCHARGE-EXCHANGE REACTIONS

The information obtained through Eqs. (33), (34), and (37) clearly is not sufficient to estimate the sizes of the deviations. In principle, the data on elastic scattering at high energies will not shed any more light on this question because one has already isolated the

TABLE II. Comparison of the general Levinson-Wall-Lipkin relation (31′) and the general Johnson-Treiman relation (25) with the experimental data. The calculation of the weighting parameters μ and λ is explained in Refs. 16 and 17.

Beam momentum (GeV/c)	Relation (31′)		Relation (25)	
	μ	z	λ	ζ
6	0.22	0.006 ± 0.04	0.49	-0.33 ± 0.09
8	0.58	0.005 ± 0.03[a]	0.10	-0.37 ± 0.05[a]
10	...	...	0.10	-0.30 ± 0.06
12	0.58	$0.04\ \pm0.04$	0.10	-0.19 ± 0.07
14	0.58	$0.03\ \pm0.05$	0.10	-0.18 ± 0.07
16	0.26	$-0.07\ \pm0.06$	0.15	-0.30 ± 0.11
18	0.03	$0.03\ \pm0.19$	0.20	-0.28 ± 0.21
		$\langle z\rangle=0.01\ \pm0.02$		$\langle\zeta\rangle=-0.25\pm0.03$

[a] This value is not considered in computing $\langle z\rangle$ or $\langle\zeta\rangle$.

[15] Most of the data we have used are taken from W. Galbraith *et al.*, Phys. Rev. **138**, B913 (1965). We have supplemented the above data by the following more precise data which have become available recently: (i) $\Delta(\pi^+p)$ in the range 8–18 GeV/c from K. J. Foley *et al.*, Phys. Rev. Letters **19**, 330 (1967); (ii) $\sigma_t(pp)$ in the energy range 8–18 GeV/c from K. J. Foley *et al.*, *ibid.* **19**, 857 (1967); (iii) from the neutron-beam experiment of M. N. Kreisler *et al.*, *ibid.* **20**, 468 (1968), we have used the extrapolated estimates $\sigma_t(pn)=37.0\pm1.2$ mb at 14 GeV/c and 37.6 ± 1.2 mb at 18 GeV/c.

[16] The weighting parameter μ is given by the expression

$$\mu=[E(K^+n)-2E(K^+p)][E(\pi^+p)+E(K^+p)+E(K^+n)]^{-1},$$

where $E(K^+n)$, for instance, denotes the error squared in $\Delta(K^+n)$.

[17] The parameter λ is given by

$$\lambda=[E(K^+p)+2E(\pi^+p)][E(K^+p)+2E(K^+n)]^{-1},$$

where E has the same meaning as in Ref. 16.

vector-meson contributions in the elastic amplitudes in considering the total cross-section relations. Therefore, we shall next turn to a discussion of the charge-exchange (CEX) and hypercharge-exchange (HCEX) reactions with a view to obtain some additional information on the parameters.

Except for the $\pi^- p$ charge-exchange reaction, there is no CEX or HCEX reaction in which a vector-meson trajectory alone is exchanged. Hence, these inelastic reactions do not provide a direct and clear test of the universality hypothesis. However, let us suppose that an analysis of the data on differential cross sections and polarizations on the CEX and HCEX reactions is made on the basis of a Regge model using vector- and tensor-meson exchanges. Then, to what extent can we make use of the vector-exchange amplitudes in such an analysis in estimating the deviations from the vector-universality hypothesis?

We have presented in Table III the Regge-pole amplitudes (at $t=0$), which are due to the exchange of a vector trajectory, for the reactions of interest. The following points should be noted: (i) For the two CEX reactions in which the ρ is exchanged, the combination of parameters is precisely that which occurred in the discussion of Johnson-Treiman relations. Thus a test of the equality between the vector residues in CEX reactions (aside from the Clebsch-Gordan factor) constitutes a test of the "universal-breaking" hypothesis [Eq. (7)]. No additional information can be obtained on any other parameters. (ii) All the K^*-exchange amplitudes describing the production of a Λ hyperon depend on the quantity $(1+\frac{1}{3}\alpha)$ where α, we recall, is the d/f parameter. Note that the N for the Λ reactions may have a different energy dependence than the N for the CEX reactions, due to the possible difference between the ρ and K^* trajectories. (iii) All the K^*-exchange amplitudes describing the production of a Σ hyperon depend on the quantity $(1-\alpha)$. Thus a clean determination of α (even in the presence of symmetry-breaking) is provided by taking the ratio of the amplitudes for the Λ reactions to those of the Σ reactions. The value of the α, thus determined from a recent analysis[18] of the CEX and HCEX reactions, turns out to have the value (assuming a conservative error)

$$\alpha=-0.16\pm0.10. \tag{38}$$

From Eqs. (37) and (38) we estimate the size of the $SU(3)$-breaking parameter to be

$$x=-0.03\pm0.03. \tag{39}$$

A reliable estimate of the parameter u is not possible due to the large uncertainty in Eq. (33), originating mainly from the poorly known values of $\sigma_t(\bar{p}n)$ at the present time. On the other hand, there does not appear to be any simple way to distinguish, by consideration of scattering experiments, between a possible failure of ω-universality hypothesis and failure of the nonet hypothesis.

[18] D. D. Reeder and K. V. L. Sarma, Phys. Rev. **172**, 1566 (1968).

TABLE III. List of the contributions at $t=0$ of the exchange of a vector-meson Regge trajectory (either ρ or K^*) to the amplitude for various reactions. The amplitudes for the reactions in parentheses are obtained by using the amplitude for the preceding reaction, with different $SU(2)$ Clebsch-Gordan coefficients. The symbols N, ζ, and α are defined through Eqs. (36), (35), and (6), respectively.

Reaction	Amplitude
$\pi^- p \to \pi^0 n$	$-(1/\sqrt{2})N(1+\zeta)$
$K^- p \to \bar{K}^0 n$	$\frac{1}{2}N(1+\zeta)$
$K^- p \to \eta\Lambda$	$\frac{3}{4}N(1+\frac{1}{3}\alpha)$
$\pi^- p \to K^0\Lambda$	$-(\frac{1}{4}\sqrt{6})N(1+\frac{1}{3}\alpha)$
$(K^- p \to \pi^0\Lambda)$	
$K^- p \to \eta\Sigma^0$	$\frac{1}{4}\sqrt{3}N(1-\alpha)$
$\pi^+ p \to K^+\Sigma^+$	$-\frac{1}{2}N(1-\alpha)$
$(\pi^- p \to K^0\Sigma^0)$	
$(K^- p \to \pi^-\Sigma^+, \pi^0\Sigma^0)$	

4. SUMMARY AND DISCUSSION

The success of the cross-section relations put forward by Levinson *et al.* have generally been regarded as a test of ω universality. On the other hand, the Johnson-Treiman relations are known to disagree systematically with experiment indicating that ρ universality may not be a valid hypothesis. In an effort to understand these facts, we have considered a model in which the possible departures from $SU(3)$ symmetry and universality are incorporated. The $SU(3)$-breaking mechanism we have envisaged here is in keeping with the spirit of the universality principle. Simple tests of this "universal" $SU(3)$-breaking hypothesis itself are provided by the equality (aside from the usual Clebsch-Gordan coefficients) of the vector-meson Regge residues at $t=0$ (i) in $\pi^- p$ and $K^- p$ charge-exchange scattering, (ii) in $\pi^- p \to K^0\Lambda$ and $K^- p \to \eta\Lambda$, and (iii) in $\pi^+ p \to K^+\Sigma^+$ and $K^- p \to \eta\Sigma^0$.

In conclusion, we would like to make the following comments: Precise data on HCEX reactions would allow us to fix the d/f parameter for the vector-meson couplings to baryons. A stringent test of the ρ universality awaits more data on pn and $\bar{p}n$ total cross sections. Accurate data on $\sigma_t(K^\pm n)$ would be valuable to estimate the $SU(3)$-breaking parameter through the Johnson-Treiman relations.

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