BAROINVARIANCE OF STRONG INTERACTIONS

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A barospin is introduced, the third component of which is equal to half the baryon charge. It is assumed that strong interactions are approximately invariant against rotations in barospin space, that is, degeneracy in the baryon charge takes place. In particular, invariance against rotation by 180° about a second axis in barospace leads to conservation of A-parity and γ_5R-invariance of strong interactions. The latter makes it possible to explain the smallness of the electrical form factor of the neutron with a magnetic form factor of the same order as that of the proton. The extension of baroinvariance to weak interactions leads to the result that for lepton decays the vector hadron current should be a component of the F-octet while the axial current should belong to the D-octet. Good agreement with experiment can be obtained also for hadron decays. Here, however, it is necessary to forego the universality of the lepton and the non-lepton weak interactions. Baroinvariance leads to the appearance of resonances or even long-lived hadrons with fully defined quantum numbers in many-baryon systems. In particular, in a two-baryon system there should exist a pseudoscalar octet.

1. INTRODUCTION

THE success of the unitary symmetry hypothesis has served as a stimulus for numerous attempts to find an even broader symmetry of strong interactions. In most such attempts one either assumes the existence of a new additive quantum number (see, for example, the review [1]), or degeneracy is postulated with respect to unitary-charge and space-spin variables of strong interactions.[2,3] In the present paper we discuss still another possibility of extending unitary symmetry.

In addition to the charge and strangeness, the degeneracy in which leads to unitary symmetry, only one conserving additive quantum number is known—the baryon charge. In the universally accepted scheme, conservation of the electric charge Q and of the baryon charge B are treated differently. The conservation of Q is related with the isotopic invariance and conservation of the third projection of isotopic spin T_3, whereas B is an isolated quantum number, connected with group U_1, for which the generator is a unit operator. In this paper, however, we shall attempt to regard the conservation of B and Q (more accurately of B and T_3)[1)] in similar fashion, introducing, in analogy with the isotopic spin, a certain "barospin" such that its projection on the third axis in "barospace", b_3, is connected with the baryon charge by the equation

$$b_3 = B / 2. \tag{1}$$

We further assume that the barospin is conserved, that is, "baroinvariance" holds true. This means that to sufficiently good approximation, strong interactions are degenerate in b_3, that is, in the baryon charge, and that certain states with different values of B, for example with B = 0 and B = ±2, should have analogous properties. On the other hand, such states have masses that differ by an amount of the order of 2 BeV/c^2. It is therefore clear that baroinvariance is admissible only to the extent to which the baryon mass can be regarded as a small quantity.

At first glance such an approximation seems impossible, but even within the framework of unitary symmetry, the mass difference within a single unitary multiplet is assumed to be a small quantity, even though it reaches values on the order of 0.4—0.5 BeV/c^2. If we treat the success of unitary symmetry as a consequence of the fact that distances that are characteristic of "very strong interaction" are of the order of $\lesssim 1/10\ m_N$ then the approximate baroinvariance can also take place. It can be noted, on the other hand, that the approximation wherein baryons have zero mass

1)The symmetry, the starting point of which is the analogy between B and Q was considered by Schwinger.[4] Lipkin[5] proposed hadron systematics based in particular on the similarity between B and the hypercharge Y.

does not of necessity lead to baroinvariance. In a paper by Gell-Mann,[6] for example, the $SU_3 \otimes SU_3$ symmetry is considered which can take place in the same approximation.

From the hypothesis concerning the degeneracy of strong interactions with respect to the baryon charge, follow several experimental consequences. Some of them can be checked in future experiments; others are in good agreement with the already available data. In particular, baroinvariance leads in natural fashion to conservation of A-parity,[7] which is an eigenvalue of the operator of rotation by 180° about the second axis in barospace. From invariance against such a transformation follows further $\gamma_5 R$ invariance, which also explains several experimental facts (the difference from [6] lies, in particular, in the fact that in the latter paper there is not $\gamma_5 R$ but γ_5 invariance). Conservation of A-parity and $\gamma_5 R$ invariance can, of course, take place also in the absence of baroinvariance, but the barosymmetrical theory appears to be more consistent.

Our exposition will be built up as follows. In Sec. 2 we give a definition of barospin and discuss the properties of baroscalar and barovector currents. In Sec. 3 we show that from baroinvariance follows conservation of A-parity and $\gamma_5 R$ invariance. Sections 4 and 5 are devoted to classification with respect to barospin and A-parity of the known mesons and meson resonances. In Sec. 6 are discussed questions of resonances in many-baryon systems. Sections 7–10 are devoted to an extension of baroinvariance (more accurately, $\gamma_5 R$ invariance) to include electromagnetic and weak interactions. In Sec. 7 it is shown that $\gamma_5 R$ invariance explains the smallness of electric form factor of the neutron along with the fact that the magnetic moments and the form factors of the neutron and proton are of the same order of magnitude. In Sec. 8 are discussed lepton, in Sec. 9 hadron, and in Sec. 10 photon decays of hyperons and mesons. In Sec. 11 we summarize the experimental situation.

2. BAROSPIN

In accordance with (1), we shall assume that the baryons and antibaryons are components of the barospinor ($b = 1/2$). Denoting such a barospinor by Ψ, we write it in the form

$$\Psi = \begin{pmatrix} \Psi_1 \\ \Psi_2 \end{pmatrix} = \begin{pmatrix} B \\ \gamma_5 C\bar{B} \end{pmatrix}. \tag{2}$$

In (2) B denotes an octet of baryons, which from the point of view of unitary spin, can be written in the form of a 3×3 matrix (the signs are chosen such that the isospinor is made up of Ξ^0 and Ξ^-):

$$B = \begin{pmatrix} \dfrac{\Lambda + \sqrt{3}\Sigma^0}{\sqrt{6}}, & \Sigma^+, & p \\ \Sigma^-, & \dfrac{\Lambda - \sqrt{3}\Sigma^0}{\sqrt{6}}, & n \\ -\Xi^-, & \Xi^0, & -\sqrt{2/3}\Lambda \end{pmatrix}. \tag{3}$$

It is implied that

$$(\Psi_1)^i{}_k = B^i{}_k, \qquad (\Psi_2)^i{}_k = \gamma_5 C\bar{B}^i{}_k = \gamma_5 C\overline{B^k{}_i}. \tag{4}$$

According to (4), Ψ_1 and Ψ_2 have identical unitary properties, otherwise the transformations of the barospin and of the unitary symmetry would not commute with each other. The presence of such commutation denotes now that we deal with a group $SU_3 \otimes SU_2$. From (4) it follows that in barorotations the operators p and $\overline{\Xi^-}$, Σ^+ and $\overline{\Sigma^-}$, Λ and $\bar{\Lambda}$, etc. are transformed one into another. Introduction in Ψ_2 of the factor γ_5 is due to several causes: primarily this is the requirement that the transformation commute with the charge-conjugation operation. With this Ψ_1 and Ψ_2 have the same space parity.

We now proceed to the question of the properties of baryon currents. From Ψ_1 and Ψ_2 we can construct in the usual fashion the barovector ($b = 1$) with components

$$\begin{aligned} b_3 &= 1: \quad \Psi_1 W \Psi_1, \\ b_3 &= -1: \quad \Psi_2 W \Psi_2, \\ b_3 &= 0: \quad (\Psi_2 W \Psi_1 + \Psi_1 W \Psi_2) / \sqrt{2} \end{aligned} \tag{5}$$

and the baroscalar ($b = b_3 = 0$):

$$(\Psi_2 W \Psi_1 - \Psi_1 W \Psi_2) / \sqrt{2}.$$

Here W denotes an operator acting on the spin and unitary variables.

Equations (5) can be written in a different form by introducing the Pauli matrices β (β_1, β_2, β_3), which act in barospin space. Then the expressions

$$\Psi i\beta_2 \beta W \Psi / \sqrt{2}, \qquad \Psi i\beta_2 W \Psi / \sqrt{2} \tag{6}$$

for the barovectors and baroscalars are valid.

If the expression $\Psi_2 W \Psi_1$ is written in the more usual form $\bar{B}OUB$, where O is the spin operator (S, P, T, V, A) and U is the unitary operator which produces from the two octets the multiplets 1, 8_d. 8_f, 10, 10*, and 27, then it follows from the equality $\Psi_2 W \Psi_1 = \bar{B}OUB$ that

$$W = -C^{-1}\gamma_5 OU. \tag{7}$$

Inasmuch as Ψ is a fermion state, Ψ_1 and Ψ_2 anticommute with each other. Therefore when $b = 1$, W should be antisymmetrical, and for

Table I. Allowed currents

Variant	$b = 1$	$b = 0$
S, P, V	$1, 8_d, 27$	$8_f, 10, 10^*$
A, T	$8_f, 10, 10^*$	$1, 8_d, 27$

$b = 0$ symmetrical. In other words, when $b = 0$ the symmetry of the spin operator $C^{-1}\gamma_5$ and of the unitary operator U should be the same, and when $b = 1$ it should be different. Thus, for specified b and O, only some unitary multiplets are allowed. The allowed multiplets are listed in Table I.

It follows from Table I, in particular, that the mass term in the Hamiltonian, which is a scalar (S) and which is represented within the SU_3 framework by the singlet (1), must have $b = 1$, that is, it transforms like the third component of a barovector. This means that the barosymmetry can be valid only in an approximation in which the baryon mass can be set equal to zero in accordance with the arguments presented in Section 1. The presence of a mass term which behaves like b_3 violates the baroinvariance, and because of it the masses of Ψ_1 and Ψ_2 must have opposite signs. Here, of course, the real states of the baryons $[B^i_k = (\Psi_1)^i_k]$ and antibaryons $[(B^i_k)^c = C\overline{B^i_k} = \gamma_5(\Psi_2)^k_i]$ have masses of equal sign.

As to the vector (V) currents in Table I, 8_f represents currents whose conservation is connected with unitary symmetry and which have $b = 0$, that is, they do not change under barotransformation. At the same time, the barovector current, the conservation of which leads to barosymmetry, is a unitary singlet. The integrals of the fourth components of these currents are generators of transformations of the group $SU_3 \otimes SU_2$. Introduction of the mass term causes only one of the three components of the unitary-singlet barovector current to be conserved, namely the one for which $b_3 = 0$. The situation here is perfectly analogous to isotopic invariance which is violated by an electromagnetic interaction which conserves only T_3.

3. γ_5R INVARIANCE

The results of the preceding section can be formulated in somewhat different form, by introducing the operation of R-transformation.[8] We shall show, first, that baroinvariance implies γ_5R invariance. To this end we consider the operation of rotation through 180° about the second axis in barospace:

$$\hat{A} \equiv \exp(i\pi\hat{b}_2). \tag{8}$$

It is easy to see that states with $b_3 = 0$, for example mesons, are eigenstates of the operator (8) with eigenvalues

$$A = (-1)^b. \tag{9}$$

The conservation of the quantum number A, the so called A-parity, was noted first by Bronzan and Low.[7] In our language it is a particular case of baroinvariance. A discussion of systems with $b_3 = 0$ will be continued in the next two sections.

For the barospinor (2), the operation (8) transforms Ψ into

$$i\beta_2\Psi = \begin{pmatrix} \Psi_2 \\ -\Psi_1 \end{pmatrix}, \tag{10}$$

where β_2 is the second Pauli matrix in barospace. Expression (10) is equivalent to the transformation

$$\hat{A}:\qquad B^i{}_k \to \gamma_5 C\overline{B^k{}_i},\qquad \overline{B^k{}_i} \to -C^{-1}\gamma_5 B^i{}_k. \tag{11}$$

Together with the charge-conjugation operation, under which

$$\hat{C}:\qquad B^i{}_k \leftrightarrow C\overline{B^i{}_k}, \tag{12}$$

(11) leads to

$$\hat{C}\hat{A}:\qquad B^i{}_k \to \gamma_5 B^k{}_i,\qquad \overline{B^k{}_i} \to -\overline{B^i{}_k}\gamma_5. \tag{13}$$

The transformation (13) has obviously the meaning of a direct product of operations of γ_5 conjugation

$$\hat{\gamma}_5:\qquad B^i{}_k \to \gamma_5 B^i{}_k,\qquad \overline{B^i{}_k} \to -\overline{B^i{}_k}\gamma_5 \tag{14}$$

and R-conjugation [8]

$$\hat{R}:\qquad B^i{}_k \to B^k{}_i,\qquad \overline{B^i{}_k} \to \overline{B^k{}_i}. \tag{15}$$

We have shown by the same token that for barospinors, that is also for arbitrary other barotensors

$$\hat{\gamma}_5\hat{R} = \hat{C}\hat{A} = \hat{C}\exp(i\pi\hat{b}_2) \tag{16}$$

and that as a consequence of baroinvariance, we should also get γ_5R invariance.

The experimental data argue against R invariance of strong interactions, as a result of which the magnetic moment of the neutron should vanish,[9] and along with the 10-multiplet there should exist a 10*-multiplet of isobars with $J^P = 3/2^+$. These two difficulties are eliminated in the framework of γ_5R invariance, where the multiplet 10* should break up into a meson and an unphysical state, differing from a baryon by a γ_5 transformation (in the meson plus baryon system, such a multiplet, generally speaking, is missing), and where the magnetic moment of the neutron differs from zero (the latter question will be discussed in greater detail in Sec. 7). We shall therefore assume from now on that the strong interaction is $\gamma_5 R$ invariant, but does not have properties of γ_5 or R invariance separately. An example of such interaction can be the expression

$$\sum_{r=1}^{8} \mathrm{Sp}\,(\Psi y \beta \Psi)\, \mathrm{Sp}\,(\Psi y \beta \lambda_r \Psi + \Psi y \beta \Psi \lambda_r) \times \mathrm{Sp}\,(\Psi y \lambda_r \Psi - \Psi y \Psi \lambda_r), \tag{17}$$

where $y \equiv i\beta_2 C^{-1}\gamma_5$, as in (6), $\beta\,(\beta_1, \beta_2, \beta_3)$ are the Pauli matrices for the barospin, λ_r are the matrices of the unitary spin, and the trace is taken over the unitary indices. The first and second factors in (17) are barovectors, and the third is a baroscalar. At the same time, the first factor is a unitary singlet, and the second and third are the octets 8_d and 8_f.

It must be emphasized that although barosymmetry implies invariance against A-transformation and $\gamma_5 R$-transformation, the inverse statement would be incorrect. An example of $\gamma_5 R$-invariant but not barosymmetrical interaction can be expression (17) in which all the vectors β are replaced by β_3. For states with $b_3 = 0$, however, the consequences of both transformations coincide. We shall henceforth deal (with the exception of Sec. 6) precisely with such systems. Therefore for most applications it is sufficient to use the assumption of $\gamma_5 R$ invariance of the strong interactions, without introducing the barospin. From our point of view, nevertheless, the baroinvariant theory is more consistent. The solution of the question of the presence of barosymmetry can be obtained by investigating systems with $b_3 \neq 0$.

Using (16), we can now write the results of Table I in a somewhat different form. To this end we introduce three sign multipliers η_c, η_5, and η_u, defined in the following fashion:

$$C^{-1}OC = \eta_c O^T, \qquad -\gamma_5 O \gamma_5 = \eta_5 O, \qquad U_{ij}^{kl} = \eta_u U_{ji}^{lk}. \tag{18}$$

It is easy to see that

$$\eta_c = \begin{cases} +1 & (S, P, A), \\ -1 & (V, T), \end{cases} \qquad \eta_5 = \begin{cases} +1 & V, A, \\ -1 & S, P, T, \end{cases}$$
$$\eta_u = \begin{cases} +1 & 1, 8_d, 27, \\ -1 & 8_f, 10, 10^*. \end{cases} \tag{19}$$

We now apply relation (16) to the current $(\bar{B}OUB)$. Inasmuch as this expression has $b_3 = 0$, it is an eigenstate of the operator (8) with eigenvalue (9). Therefore relation (16) can be written in the form

$$\eta_c \eta_5 \eta_u = (-1)^b. \tag{20}$$

Equation (20) is equivalent to Table I.

4. PSEUDOSCALAR AND VECTOR MESONS

Meson states have a zero baryon charge, that is, $b_3 = 0$. They should have an integer barospin. Confining ourselves to states with $b = 0$ and $b = 1$, which can interact with baryon currents, we ascribe to the known pseudoscalar and vector mesons the barospin values listed in Table II.

The grounds for this are as follows.

1. Within the framework of barosymmetry, the baryon mass is assumed to be a small quantity. It is therefore reasonable to neglect also the meson mass. The vector fields and the corresponding mesons are then naturally related to the conserving currents in the sense of Yang and Mills[10] and Sakurai[11]. Then, as already noted, for the vector octet $b = 0$ and for the singlet $b = 1$. In the latter case there should exist also vector hadrons with $b_3 = \pm 1$, i.e., with baryon charge $B = \pm 2$. We shall return to the question of states of this kind in Sec. 6.

It must be noted that, according to (9), the vector octet now has $A = +1$ and the singlet has $A = -1$. It is precisely these values of A-parity which were ascribed to vector mesons by Bronzan and Low[7] on the basis of phenomenological considerations.

2. It is natural to ascribe to the pseudoscalar octet $b = 1$ for two reasons. First, the pseudoscalar mesons interact with the baryons more readily via D-coupling which is in better agreement with experiment, than F-coupling.[8,12,13] According to Table 1, this leads to $b = 1$. Second, it is precisely when $b = 1$ that the pseudoscalar mesons have a correct (negative) value of A-parity.

As noted by Bronzan and Low[7], conservation of A-parity forbids the following decays [for the

Table II. Pseudoscalar and vector mesons

J^P	Mesons	Unitary multiplet (the corresponding baryon current is in the parentheses)	b	$A = (-1)^b$
0^-	π, η, K	$8\,(8_d)$	1	-1
	χ	$1\,(-)$	0	$+1$
1^-	ρ, φ, K^*	$8\,(8_f)$	0	$+1$
	ω	$1\,(1)$	1	-1

gamma quantum $b = 0$, that is, $A = +1$ (see Sec. 7)]:

$$\varphi \to \rho + \pi, \quad \varphi \to 3\pi, \quad \eta \to 2\gamma \quad \eta \to \pi^+ + \pi^- + \gamma; \quad K^* \to K + 2\pi, \quad K^* \to K + \gamma, \tag{21}$$

whereas the decays

$$\rho \to 2\pi, \quad K^* \to K + \pi, \quad \omega \to \pi^+ + \pi^- + \pi^0, \quad \omega \to \pi^0 + \gamma$$

are allowed. In experiment, the decays (21) are actually suppressed in one degree or another. Consequently, in this respect baroinvariance agrees with experiment.

An additional check on A-parity conservation can be the experimental confirmation of the inequalities [7]:

$$\begin{gathered}\Gamma(\omega \to e^+ + e^-) / \Gamma(\varphi \to e^+ + e^-) \ll 1, \\ \Gamma(\rho \to \pi + \gamma) / \Gamma(\omega \to \pi^0 + \gamma) \ll 1, \\ \Gamma(\varphi^0 \to \pi^0(\eta) + \gamma) / \Gamma(\omega \to \pi^0(\eta) + \gamma) \ll 1, \\ \Gamma(K^* \to K + \gamma) / \Gamma(\omega \to \pi^0 + \gamma) \ll 1.\end{gathered} \tag{22}$$

3. In Table II the value $b = 0$, and consequently a positive A-parity, is ascribed to the pseudoscalar singlet χ [resonance in the system $\eta 2\pi$ or $\gamma 2\pi$ with $m = (957.5 \pm 1.5)\ \mathrm{MeV/c^2}$ and $\Gamma \leq 4$ MeV[14 16]]. In this case the decay $\chi \to \pi\pi\eta$ is forbidden while $\chi \to \pi\pi\gamma$ is allowed. This explains the following two experimental facts: approximately the same order of magnitude of the probabilities of both decays of χ, although only the probability of the photon decay contains the small factor $\alpha = 1/137$ [in experiments $\Gamma(\chi \to \pi^+\pi^-\gamma)/\Gamma_\chi = 0.22 \pm 0.04$[14]], and the small resonance width. In the table compiled by Rosenfeld et al.[17] it is also assumed that $A_\chi = +1$. We note, finally, that when $b = 0$ the pseudoscalar singlet cannot interact with the baryon current. Such an interaction can take place in the case when χ is a member of a new pseudoscalar octet.

To conclude this section, let us discuss the $\omega-\varphi$ mixing. In order to explain the absence of decays $\varphi \to \rho + \pi$ and $\varphi \to 3\pi$, we should ascribe to φ a definite value of b or of A-parity ($b = 0$, $A = +1$). The latter is possible only if the $\omega-\varphi$ mixing is small and can be ignored. On the other hand, it is known that for the vector octet the Gell-Mann—Okubo relation is not satisfied. This fact is customarily attributed to the presence of mixing.[18] In the absence of the latter, it becomes necessary to assume that the unitary mass formula is not a sufficiently good approximation, at any rate for mesons. It must be noted in this connection that the degree of agreement of such a formula with experiment is at present more mystical than a result of theoretical principles. In addition, the assumption that nonsatisfaction of the Gell-Mann—Okubo relation for the vector octet is connected with the $\omega-\varphi$ mixing remains so far unconfirmed, inasmuch as the known experimental data suffice only for the determination of the mixing parameters.

Experimental evidence in favor of the presence or absence of $\omega-\varphi$ mixing can be obtained by studying the decay $K^* \to K + 2\pi$. If such mixing does take place, then, by knowing its parameters, and also the probabilities of the decays $\varphi \to 3\pi$ and $\omega \to 3\pi$, we can calculate with the aid of the unitary symmetry relations the probability of the decay $K^* \to K + 2\pi$. Such a calculation was made by Geshkenbeĭn and Ioffe.[19] It turned out that in the presence of mixing

$$\xi \equiv \Gamma(K^* \to K + 2\pi) / \Gamma(K^* \to K + \pi) \approx 0.1\%. \tag{23}$$

On the other hand, if baroinvariance takes place, or if at least A-parity is conserved, then the decay $K^* \to K + 2\pi$ is forbidden. We should expect here a much lower value for ξ, since in (23) the probability of such a decay contained no small parameters. An experimental verification of (23) will probably become possible in the nearest future. At the present time, according to [17], $\xi \leq 0.2\%$. A direct verification of the mixing hypothesis would also be a determination of the quantity $\Gamma(\omega \to e^+e^-)/\Gamma(\varphi \to e^+e^-)$. In the presence of $\omega-\varphi$ mixing, this ratio should be $\sim m_\omega/2m_\varphi = 0.4$, whereas for A-parity conservation it should be much smaller.

5. NEW MESONS

Recently there have been many communications on hadrons that decay into vector and pseudoscalar mesons. Experimental data, taken from the table in [17] and from the review papers at the Dubna conference,[20,21] are listed in Table III.

The existence of such hadrons, with the possible exception of A_1 and A_2, can hardly be regarded as finally established. Nonetheless, it is of interest, taking the existence of the resonances of Table III on faith, to present their systematics with respect to unitary spin and barospin.

1. So long as ω is a unitary singlet with $b = 1$, the resonance B should enter in the unitary octet with $b = 0$ or 2 ($A = +1$).[22,23] To this octet there should belong also the isosinglet and isospinor resonances which decay most likely into $\omega + \eta$ and $\omega + K$.

2. The system $\rho\pi$ has $A = -1$, whereas for $K\bar{K}$ or $\eta\pi$ we have $A = +1$. It follows, therefore, that either part of the decays of A_2 proceeds with non-conservation of barospin and A-parity (this

Table III. Resonance states of vector and pseudovector mesons

Designation	Mass, MeV/c²	Width-MeV	T^G	Most probable J^P	Decay channels	Relative probability percent	b	Unitary multiplet
B	1215 ± 18	122 ± 7	1^+	1^+ or 2^-	$\omega\pi$	~100	0 or 2	8
A_1	1080 ± 10	100	1^-	1^+ or 2^-	$\rho\pi$	~100	1	8
A_2	1310 ± 15	90	1^-	2^+	$\rho\pi$	~60	1	?
					$K\bar{K}$	~20		
					$\eta\pi$	~20		
H	975 ± 15	120	0^-	1^-	$\rho\pi$	~100	1	?
E	1415 ± 15	70	0^-	1^-	$K^*\bar{K}+K\bar{K}^*$	~100	1	8
C	1215 ± 15	60 ± 10	$^1/_2$ or $^3/_2$	1^+ or 2^-	$K^*\pi$	~50	1	8
					$K\rho$	~50		
$K\pi\pi)$	1270 ± 20	60 ± 20	$^3/_2$		$K^*\pi$	~75	1	10* or 27
					$K\rho$	~25		—

is more likely to pertain to the decays $A_2 \to K + \bar{K}$ and $A_2 \to \eta + \pi$, where for the same or even larger phase volume the probability is smaller than for $A_2 \to \rho + \pi$; in this case A_2 has $b = 1$ and $A = -1$), or else one observes in fact near 1300 MeV/c^2 not one but two resonances with zero strangeness.

3. All the remaining hadrons in Table III decay into a vector meson with $b = 0$ and a pseudoscalar meson with $b = 0$. If their decays occur with barospin conservation (an argument in favor of this assumption are the sufficiently large widths), then all have $b = 1$ ($A = -1$).

4. The latest experimental data [24] agree best of all with E-resonance quantum numbers $J^{PG} = 1^{--}$, the same as for ω and φ. It is difficult to understand here, however, why there are no decays $E \to \rho + \pi$ or $E \to K + \bar{K}$. We prefer to assume that E has quantum numbers 1^{++} or 2^{-+}. In this case it is natural to attempt to unify A, E, and C in a unitary octet, ascribing to them all identical J^P and putting $T_C = \frac{1}{2}$. The mass formula assigns to m_C a value ~ 1340 MeV/c^2, which does not agree with experiment, but the same formula is poorly applicable also to the octet of vector mesons. At the same time, the octet hypothesis prescribes (for $J^P = 1^+$, when the system V + P is in an s-state and the matrix element of the decay can be assumed to be a constant), a ratio of widths

$$\Gamma(A_1 \to \rho\pi) : \Gamma(E \to K^*\bar{K} + K\bar{K}^*) : \Gamma(C \to K^*\pi)$$
$$= 2.6 : 2 : 1,$$

which is in sufficiently good agreement with the experimental data in Table III.

5. As to the resonance in the $K^*\pi$ or $K\rho$ system with $T = \frac{3}{2}$, if it actually exists, then it should enter in a unitary multiplet 10 or 27 with $b = 1$, $A = -1$.

6. STATES WITH $b_3 \neq 0$

Baroinvariance requires that states with different baryon charges have analogous properties. In particular, hadrons with $b = 1$ should exist not only as mesons ($b_3 = 0$), but also in the state with $b_3 = 1$, that is, in a two-baryon system. According to Table II, for example, in such a system one should observe a vector singlet and a pseudoscalar octet. The singlet should have a strangeness $S = -2$; the terms of the octet can be obtained in systems with $S = -1$, -2, and -3. The same remark holds true also for the more problematic states with $b = 1$, discussed in the preceding section. The existence or absence of the indicated hadrons in the two-baryon system would be decisive evidence in favor or against baroinvariance.

There are two communications concerning resonant-type phenomena in a two-baryon system with $Y = 1$, i.e., $S = -1$. Piroque[25] reports a resonance with $m \approx 2.36$ BeV/c^2. Sechi-Zorn et al [26] found a peak in the Λp-scattering cross section near threshold at $m = 2.063$ BeV/c^2 (however, Alexander et al[27] observed no such peak). It would apparently be premature to regard these resonances as reliable.

As to the deuteron and the singlet resonance in nucleon-nucleon scattering, both states have $Y = 2$ and can enter only in unitary multiplets 10* (deuteron) and 27 (singlet). Many authors (see, for example,[28,29]) discussed the question of other members of such multiplets. From the point of view of barosymmetry, one should also presume the existence of corresponding meson resonances, forming the 10 and 10* multiplet (the so called icosuplet [30]) with $J^P = 1^+$ and the 27 multiplet with $J^P = 0^+$. On the other hand, both for the deuteron and for the singlet, an important part is played by nucleon-nucleon interactions at large distances, where the contribution of the interaction that breaks unitary symmetry can hardly be regarded small. If indeed such an interaction leads to the formation of a deuteron and a singlet, the search for their unitary and barospin analogs becomes meaningless. The same holds true also for nuclei with higher b_3. Evidence in favor of this point of view is the well-known fact that both for ordinary nuclei and for hypernuclei the binding energy is small, although the masses of the nucleon and of the Λ hyperon differ quite strongly. We therefore assume that the nuclei and the hypernuclei (and also the near-threshold resonances of the singlet type in NN scattering) are produced as a rule as a result of non-baryon-invariant interaction, and do not enter in the baromultiplets.

We now proceed to the three-baryon system. Numerous resonances in the system baryon + pseudoscalar meson, for which $b_3 = 1/2$, can have a barospin which is either $b = 1/2$ or $b = 3/2$. In the latter case, one should observe in the three-baryon system, where $b_3 = 3/2$, their analogs (say, a decuplet with $J^P = 3/2^+$). Observation of such states, however, is made difficult by the fact that they should have a large negative strangeness. For isobars with $b = 3/2$, the decay into a baryon and vector meson (other than ω) is forbidden, even if such a decay is allowed by energy conservation or is virtual.

In the lowest approximation in the interactions that break the baroinvariance and unitary symmetry (the latter is assumed to be a component of a unitary octet), we can write the generalized formula of Gell-Mann—Okubo for the hadron masses inside the $SU_3 \otimes SU_2$ multiplet. In the case of fermions

$$M = |B\{a + d[T(T+1) - Y^2/4]\} + cY|. \tag{24}$$

Here $B = 2b_3$ as the baryon charge; the constants a, d, and c are specific for the given $SU_3 \otimes SU_2$ multiplet. For bosons, whose mass can in principle differ from 0 even in the baroinvariant approximation,

$$m^2 = a_0 + d_0[T(T+1) - Y^2/4] + cBY + B^2\{a_1 + d_1[T(T+1) - Y^2/4]\}. \tag{25}$$

For octets with $b \geq 3/2$ formula (24) prescribes an identical distance between the masses of two isospinors (of the type N and Ξ), both in the one-baryon and in the three-baryon systems. For fermion states with $Y = 0$, the mass turns out to be proportional to the baryon charge. Inclusion of the term $\sim B^2$ in (25) is essential, for otherwise, for example, hadrons with baryon charge 2 would have too small a mass, as a result of which one should observe a weak deuteron decay. The absence of such a type of decay of nuclei gives grounds for assuming that a_1 is of the order of (or larger than) the square of the baryon mass.

It must be emphasized that baroinvariance, within the framework of which the masses of the baryons must be regarded equal to zero, is a very crude approximation. Therefore the relations obtained from (24) and (25) for the masses may be strongly violated.

Inasmuch as we do not include nuclei in the baromultiplets, the members of the latter should be unstable. If their mass is sufficiently large, they will decay into baryons (or baryons and mesons) as a result of strong interaction and can be observed only as resonances in a multibaryon system. We can, for example, seek two-baryon analogs of π, η, and K mesons (we denote them by π_B, η_B, and K_B) in the reactions

$$\begin{aligned} &p + p \to K_B^+ + K^+ \to \Lambda + p + K^+, \\ &\quad d + \bar{K}^0 + K^+, \quad p + p \to \pi_B^0(\eta_B) + 2K^+ \to 2\Lambda \\ &\quad + 2K^+, \quad \Xi^- + p + 2K^+, \quad p + p \to \pi_B^+ + K^+ \\ &\quad + K^0 \to \Lambda + \Sigma^+ + K^+ + K^0, \quad \Xi^0 + p + K^+ + K^0. \end{aligned} \tag{26}$$

Reactions of the same type are possible also in collisions between π or K mesons and deuterons.

If the hadron mass is below threshold for the corresponding strong decay, such a hadron is long-lived and can be observed from its track, similar to other elementary particles. The decay of a long-lived hadron will occur as a result of weak interactions. The possible decays are

$$\begin{aligned} K_B^+ &\to 2n + e^+ + \nu, \quad p + n; \\ \pi_B^0(\eta_B) &\to \Sigma^- + n + e^+ + \nu, \quad \Sigma^- + p; \\ \pi_B^+ &\to \Lambda + n + e^+ + \nu, \quad \Lambda + p \end{aligned} \tag{27}$$

etc. In the investigation of production of strange particles on nuclei, no long-lived hadrons with $S = -1$ and $S = -2$ were observed, if we disregard hypernuclei with small binding energy, inasmuch as the latter are more likely not to enter in any baromultiplet. Therefore we can assume that the described situation is not realized, at any rate in two-baryon systems.

7. ELECTROMAGNETIC INTERACTION

The extension of baroinvariance, (more accurately, $\gamma_5 R$ invariance) to include the electromagnetic interaction makes it possible to obtain several consequences which are in good agreement with experiment. We note first of all that in barotransformations, states with identical unitary indices, of the type p and $\overline{\Xi^-}$, go over into each other. Such states have the same electric charge. Therefore the electromagnetic interaction is invariant against barotransformations, if the gamma quantum has b = 0 and the operators of the electromagnetic field do not change under barotransformation. The same fact can be expressed in a different manner, noting that the gamma quantum interacts with the 8_f current of baryons, and the latter, in accordance with Table I, is a baroscalar. It is also seen from Table I that when b = 0 the gamma quantum cannot interact with the unitarily singlet current. Consequently, baroinvariance is incompatible with the existence of supercharged particles.

Having b = 0 and being charge-odd, the gamma quantum is the eigenstate of the operator of γ_5R transformation with eigenvalue −1. Therefore in the baroinvariant approximation, for arbitrary momentum transfers, the electric form factor of the baryons is represented by the F current, and the magnetic form factor by the D current. From the first statement it follows immediately that the electric form factor of the neutron should be equal to 0. Experimentally it is actually small (see, for example, the review by Ramsay[31]). From the second statement it follows that the dependence of the magnetic form factors of the baryons, including the proton and neutron, on the momentum transfer should be the same. In addition, between the anomalous magnetic moments the following relations should be satisfied:

$$\begin{aligned}\mu(p) &= -{}^1/_2\mu(n) = -\mu(\Lambda) = \mu(\Sigma^+)\\ &= \mu(\Sigma^0) = \mu(\Sigma^-) = 1/\sqrt{3}\mu(\Sigma^0\Lambda)\\ &= -{}^1/_2\mu(\Xi^0) = \mu(\Xi^-).\end{aligned} \tag{28}$$

Relations (28) differ from the equations of unitary symmetry[9] in containing one additional relation, corresponding to the absence of F-current. In order to obtain the observed values (in nucleon magnetons) $\mu(p) = 1.79$ and $\mu(n) = -1.91$, we must assume that, in the notation of Gell-Mann,[6] the contribution to the magnetic moments from the D-current is $\alpha = 0.775$ and the contribution from the F-current is equal to $1 - \alpha = 0.225$. In the notation $8_d \cdot \cos\theta + 8_f \cdot \sin\theta$ this is equivalent to $\theta = 17°$. The experimental smallness of the contribution from the F-current to the expression for the magnetic moments and of the D-current for the charges can be interpreted as serious evidence in favor of the γ_5R invariance of strong interactions.

Let us now write out a more general expression for the magnetic moments, valid not only in the zeroth but also in the first approximation in the interaction that breaks barosymmetry. Such an expression is an obvious generalization of the Oakes formula[32] and can be written in the form

$$\mu = \mu_0 D + \mu_1 BQ, \tag{29}$$

for μ_0 and μ_1 are constants, Q—the particle charge, and

$$\begin{aligned}D = U(U+1) - Q^2/4 - {}^2/_3(p-q)Q\\ - {}^1/_9(p^2+q^2+pq+3p+3q).\end{aligned} \tag{30}$$

In (30) p and q are numbers characterizing the SU_3 multiplet, and U is the value of the U-spin for the given particle.

Finally, within the framework of unitary symmetry, in first order in the electromagnetic interaction and in the interaction that breaks the baroinvariance, the following expression holds for the fermion mass

$$M = B(M_1 + M_2D + M_3D^2 + M_4Q^2) + Q(M_5 + M_6D). \tag{31}$$

For bosons we have

$$\begin{aligned}m^2 = &(m_1^2 + m_2^2D + m_3^2D^2 + m_4^2Q^2)\\ &+ BQ(m_5^2 + m_6^2D)\\ &+ B^2(m_7^2 + m_8^2D + m_9^2D^2 + m_{10}^2Q^2).\end{aligned} \tag{32}$$

The use of the last relations, as well as the analogous equations for quadrupole moments etc, may be possible for hadrons with $b \geq {}^3/_2$, provided they live long enough.

8. WEAK INTERACTION. LEPTON DECAYS.

If we start with the analogy between the electromagnetic and β-decay currents, then it is natural to assume that for the hadron currents which enter in the weak-interaction Hamiltonian b = 0, i.e., the same value of the barospin as for the electromagnetic current. According to Table I, this means immediately that, being a component of the unitary octet, the vector current should be an F-current and the axial current should be predominantly a D-current. Comparison with the experimental data leads precisely to such a conclusion.[33,34]

The condition b = 0 for hadron currents now forbids the decays $K_{\mu 2}$, K_{e4}, $\pi_{\mu 2}$ and π_{e2}. The decays $K_{\mu 3}$, K_{e3}, and π_{e3} are allowed. A certain suppression of two-lepton decays of K and π mesons was noted also earlier. In particular, Goldberg and Treiman[35] related it with the fact that in the calculation with the aid of the low-energy dispersion relations, the probability of $\pi_{\mu 2}$ decay turns out to be inversely proportional to the square of the strong-interaction constant $g^2/4\pi \approx 15$.

The extension of baroinvariance to include leptons suggests itself. If the lepton is a barospinor of type (2) with components

$$\Psi^{-}=\begin{pmatrix} e^{-} \\ \gamma_5\mu^{-} \end{pmatrix}, \quad \Psi^{0}=\begin{pmatrix} \nu_e \\ \gamma_5\nu_\mu \end{pmatrix}, \tag{33}$$

then the usual lepton current

$$(\bar{\nu}_e\gamma_\alpha(1+\gamma_5)e)+(\bar{\nu}_\mu\gamma_\alpha(1+\gamma_5)\mu) \tag{34}$$

also has b = 0. Within the framework of such a scheme, the presence of two sorts of leptons, which differ only in the mass term, becomes "natural." In this plan, however, it remains unclear why the mass of the neutral leptons is zero.

In accordance with (33) we can introduce an R-transformation for leptons. Upon rotation through 180° about the second axis in barospace, we have

$$\hat{A}: \begin{matrix} e^{-}\to\gamma_5\mu^{-}, & \nu_e\to\gamma_5\nu_\mu, \\ \mu^{-}\to-\gamma_5 e^{-}, & \nu_\mu\to-\gamma_5\nu_e. \end{matrix} \tag{35}$$

Therefore under the operation of γ_5R conjugation we have

$$\hat{\gamma}_5\hat{R}=\hat{C}\hat{A}: \begin{matrix} e^{-}\leftrightarrow\gamma_5\mu^{+}, & \nu_e\leftrightarrow\gamma_5 C\bar{\nu}_\mu, \\ \mu^{-}\leftrightarrow-\gamma_5 e^{+}, & \nu_\mu\leftrightarrow-\gamma_5 C\bar{\nu}_e. \end{matrix} \tag{36}$$

Assuming that under γ_5 inversion

$$\hat{\gamma}_5: \begin{matrix} e^{-}\to\gamma_5 e^{-}, & \nu_e\to\gamma_5\nu_e, \\ e^{+}\to-\gamma_5 e^{+}, & \bar{\nu}_e\to-\bar{\nu}_e\gamma_5, \\ \mu^{-}\to-\gamma_5\mu^{-}, & \nu_\mu\to-\gamma_5\nu_\mu, \\ \mu^{+}\to\gamma_5\mu^{+}, & \bar{\nu}_\mu\to\bar{\nu}_\mu\gamma_5, \end{matrix} \tag{37}$$

we find that for the R-transformation

$$\hat{R}: \begin{matrix} e^{-}\leftrightarrow\mu^{+}, & \nu_e\leftrightarrow C\bar{\nu}_\mu, \\ \mu^{-}\leftrightarrow e^{+}, & \nu_\mu\leftrightarrow C\nu_e. \end{matrix} \tag{38}$$

All the known interactions of leptons, except the mass term, are invariant against transformations (35)—(38). In addition, as is well known, we can admit of the equality

$$\nu_e=C\bar{\nu}_\mu. \tag{39}$$

Baroinvariance for leptons coincides in essence with the symmetry considered by Feĭnberg and Gursey.[36] The only difference is that in analogy with (2) we include in (33) the factor γ_5 which is not significant, for in the zero-mass approximation γ_5 invariance takes place for leptons. It must be noted, however, that the extension of the barospin concept to the leptons does not lead to any new limitations for their electromagnetic or weak interaction.

9. WEAK INTERACTION. HADRON DECAYS

As usual, for hadron decays the situation is more complicated. If the Hamiltonian of the weak interaction responsible for such decays is a product of the same currents which enter in the expression for the lepton decays, then such a Hamiltonian is a baroscalar (b = 0, A = +1). In this case, in the baroinvariant approximation, the decay K → 2π is forbidden, regardless of "unitary" properties of the decay Hamiltonian. The K → 3π decay is allowed. If baroinvariance of strong interactions is violated by an expression that conserves unitary symmetry, the process K → 2π remains forbidden under the condition that the decay Hamiltonian satisfies the relation $\mathfrak{S}$P = +1, where $\mathfrak{S}$ is the quantum number introduced by Gell-Mann,[37] and having the meaning of charge parity for the components of a unitary multiplet with T_3 = Y = 0.[37-39] In particular, such a property is possessed by the octet formed as a result of multiplication of V,A currents.[37]

Consequently, within the framework of the universal "current × current" scheme the decay K_1^0 → 2π is doubly forbidden. In experiment, however, such a decay is not at all strongly suppressed (see, for example,[40]). Therefore the assumption that non-lepton weak interaction has b = 0 does not look very good, at any rate for its "parity nonconserving" part responsible for the K → 2π decay. The situation is improved if this part of the non-lepton interaction has b = 1 and there is no barospin forbiddeness for such a decay.

An analogous result is obtained also from a consideration of hadron decays of hyperons of the type

$$Y\to N+\pi, \tag{40}$$

to which we now proceed. We first make two assumptions. First, following [41,38,37] we assume that the non-lepton weak interaction is a component of a unitary octet. Such an assumption, as is well known, is a natural "unitary" generalization of the ΔT = ½ rule for hadron decays. The weight functions of the three particles participating in the reaction (4) are also components of octets. The construction of a unitary octet from three others can be realized in eight ways. The number of possibilities, however, decreases if we make a second supplementary assumption that the decay Hamiltonian has the property $\mathfrak{S}$P = +1. In the paper of Gell-Mann,[37] this property was obtained as a consequence of the hypothesis concerning the "current × current" structure for nonlepton interaction. Inasmuch, however, as we assume that the decay Hamiltonian can have b ≠ 0, we must forego such reasoning. On the other hand, in the experiment [42,43] a non-lepton weak interaction was observed with $\Delta S = 0$. We might think that this interaction is a second component of the same octet, in which the Hamiltonian responsible for the reaction of the type (40) with $\Delta S = 1$ enters. For the component with $\Delta S = 0$, $\mathfrak{S}$ coincides with the charge parity C. Therefore, if there is invariance against combined inversion ($CP = +1$), then the decay interaction actually has the property $\mathfrak{S}P = +1$.

We now write down the amplitude of the decay (40) in the form.

$$(\bar{u}_N (S + P\gamma_5) u_Y) \varphi_\pi, \tag{41}$$

where S and P are constants proportional to the amplitudes of the decay Y respectively in the s and p state of the system $N + \pi$; in the second case the parity is conserved (by definition) but not in the first. The condition $\mathfrak{S}P = +1$ leaves only part of the eight possibilities for the construction of the octet of the three groups of eight in (41). The permissible ones are

$$\begin{aligned} &\text{s-wave:}\quad 8_{df},\quad 8_{ff},\quad 10 + 10^*,\\ &\text{p-wave:}\quad 1,\quad 8_{dd},\quad 8_{fd},\quad 10 - 10^*,\quad 27. \end{aligned} \tag{42}$$

The numbers denote here the dimensionality of the unitary multiplet, to which the baryon current in (41) belongs. For the octet the first index denotes the method of constructing such a current, and the second how the octet is constructed from the baryon current and pseudoscalar meson.

A further decrease in the number of possibilities in (42) can be obtained under concrete assumptions concerning the barospin properties of the decay interaction. Reaction (40) can be brought about by an interaction with $b = 0$ or 2 ($A = +1$), or with $b = 1$ ($A = -1$). In either case there remain not more than two possibilities for the construction of an octet from the three groups of eight, if we note that the singlet 1 does not make any contribution to the matrix element with $\Delta S \neq 0$. These possibilities are listed in Table IV.

Table IV. Relations between the form factors of hadron decay of hyperons

Variant	b	$A = (-1)^b$	Allowed multiplets	Relations
s-wave	0 or 2	$+1$	8_{df}	$-S_\Lambda = S_\Xi = S_0/\sqrt{3}$, $S_+ = 0$
	1	-1	8_{ff}, $10+10^*$	$S_\Lambda = S_\Xi = S_0\sqrt{3}$
p-wave	0 or 2	$+1$	1, 8_{dd}, 27	$-P_\Lambda = P_\Xi = P_0/\sqrt{3}$
	1	-1	8_{fd}, $10-10^*$	$P_\Lambda = P_\Xi = \sqrt{3/2}P_- + \sqrt{1/6}P_+$

We now proceed to consider concrete decays of the type (40):

$$\begin{aligned} &\Lambda \to p + \pi^- &&(S_\Lambda,\ P_\Lambda)\\ &\Xi^- \to \Lambda + \pi^- &&(S_\Xi,\ P_\Xi)\\ &\Sigma^+ \to p + \pi^0 &&(S_0,\ P_0)\\ &\Sigma^+ \to n + \pi^+ &&(S_+,\ P_+)\\ &\Sigma^- \to n + \pi^- &&(S_-,\ P_-). \end{aligned} \tag{43}$$

The parentheses indicate here the symbols for the corresponding constants. The presence of only two (one) independent amplitudes in Table IV implies the existence of three (four) relations between the five scalar or pseudoscalar constants in (43). One of them, namely,

$$S_0 = (S_- - S_+)/\sqrt{2},\qquad P_0 = (P_- - P_+)/\sqrt{2}, \tag{44}$$

follows already from the $\Delta T = 1/2$ rule and from isotopic invariance.[44] The remaining relations are listed in Table IV. They must be compared with the already available experimental data. According to Stevenson et al[45] in units of $5 \times 10^5\ \mathrm{sec}^{-1/2} m_\pi^{-1/2}$ we have

$$\begin{aligned} &10S_\Lambda = 3.09 \pm 0.10, \qquad P_\Lambda = 2.02 \pm 0.26,\\ &10S_\Xi = 4.09 \pm 0.18, \qquad P_\Xi = -1.41 \pm 0.12,\\ &10S_0 = \begin{cases} 3.39 \pm 0.59 & (\gamma_0 > 0),\\ 2.0 \pm 0.9 & (\gamma_0 < 0), \end{cases}\\ &P_0 = \begin{cases} -2.1 \pm 0.9 & (\gamma_0 > 0),\\ -3.5 \pm 0.5 & (\gamma_0 < 0). \end{cases} \end{aligned} \tag{45}$$

The ambiguity in the determination of S_0 and P_0 is connected with fact that for the $\Sigma^+ \to p + \pi^0$ decay the sign of the asymmetry coefficient γ has not yet been determined. In (45) the constants S are assumed positive by definition; on the other hand, the sign of the product SP (which coincides with the sign of the asymmetry coefficient α) is strictly defined. The difference in the signs of α_Λ and α_Ξ makes it necessary now to exclude the possibility of identical A-parity for the s- and p-waves in Table IV. Further, in the case when $A = +1$ for the s-wave and $A = -1$ for the p-wave, the relation between S_0 and S_Λ (or S_Ξ), and also between P_0 and P_Λ (or P_Ξ) does not agree with experiment, if we take account of (44) and of the experimental fact that either P_+ or P_- must be small.

There remains only one possibility, namely:

$$\begin{aligned} &\text{s-wave (parity nonconservation):}\\ &\quad b = 1,\quad A = -1,\\ &\text{p-wave (parity conservation):}\\ &\quad b = 0 \text{ or } 2,\ A = +1. \end{aligned} \tag{46}$$

In this case

$$S_\Lambda = S_\Xi = \sqrt{3}S_0 \qquad (b=1),$$
$$-P_\Lambda = P_\Xi = P_0/\sqrt{3} \qquad (b=0 \text{ or } 2). \tag{47}$$

It can be noted that equations (47) should take place also in the case when we start from the assumption that the decay interaction is a component of an octet with $\mathfrak{S}P = -1$. More accurately, when $\mathfrak{S}P = -1$ there follow from (46) the relations

$$S_\Lambda = S_\Xi = \sqrt{3/2}S_- + \sqrt{1/6}S_+ \qquad (b=1),$$
$$-P_\Lambda = P_\Xi = P_0/\sqrt{3}, \quad P_+ = 0 \qquad (b=0 \text{ or } 2), \tag{48}$$

however the absence of asymmetry of the decay $\Sigma^\pm \to n + \pi^\pm$ in the presence of asymmetry for $\Sigma^+ \to p + \pi^0$ means that either $P_+ = S_- = 0$ or $P_- = S_+ = 0$. Only the first equality agrees with (48). Then, according to (44)

$$\sqrt{3/2}S_- + \sqrt{1/6}S_+ = S_0\sqrt{3},$$

and (48) reduces to (47).

The correspondence between (47) and the experimental data of [45] is perfectly satisfactory, especially if we take into consideration the crudeness of the baroinvariant approximation and the fact that in many experimental papers (listed, for example, in the paper by Ticho [46]) the values obtained for the asymmetry coefficient $|\alpha_\Xi|$, meaning also P_Ξ are larger than in [45]. Agreement between (47) and (45) is obtained when $\gamma_0 < 0$. It would be desirable to check the latter inequality experimentally.

As a result of CP invariance and the equality $A = \gamma_5 RC$ (46) it follows that the decay interaction satisfying all the foregoing requirements has the property of $\gamma_5 R$ invariance. The condition $b = 1$ for that part of the interaction which does not conserve parity coincides with the result obtained at the beginning of this section in the analysis of $K \to 2\pi$ decay. Assuming $b = 1$, we essentially forego the universality of the weak interactions, inasmuch as the currents from which the lepton and non-lepton Hamiltonians are constructed turn out to be different. The foregoing of universality, in fact, is already contained in the $\Delta T = 1/2$ rule for hadron decays, since experiments on lepton decays offer evidence that there are no neutral currents. In this sense, we are forced to treat the non-universality of weak interactions as an experimental fact.

In conclusion we note that the matrix element for the decay (40) can be written not in the scalar form (41) but in the vector form

$$(\bar{u}_N\gamma_\alpha(V - A\gamma_5)u_Y)q_\alpha\varphi_\pi, \tag{49}$$

where q_α is the pion momentum and V and A are constants with

$$S = V(m_Y - m_N), \qquad P = A(m_Y + m_N).$$

The form (41) is more reasonable, for in the baroinvariant approximation, when $m_Y = m_N = 0$, the matrix element (49) vanishes. Nonetheless, the entire reasoning which was presented for (41) can be used also for the case (49) in order to establish a relation between the constants V and A. The best agreement with experiment is obtained when the non-lepton weak interaction (including its parity-conserving part) is a component of a barovector ($b = 1$; $A = -1$). Then relations (47) are valid, with S replaced by V and P by A. Again there is no universality of weak interactions.

10. WEAK INTERACTION. PHOTON DECAYS

We consider decays of the type

$$Y \to N + \gamma, \tag{50}$$

in which both weak and electromagnetic interactions participate. Both are $\gamma_5 R$ invariant. Therefore, writing down the matrix element of the decay (50) in the form

$$(\bar{u}_N\gamma_\alpha(V - A\gamma_5)u_Y)e_\alpha, \tag{51}$$

where V and A are constants, and noting that for a gamma quantum $\gamma_5 R = -1$, we should stipulate that the baryon current in (51) also satisfy the condition $\gamma_5 R = -1$. After this it turns out to be a superposition of multiplets

$$8_f, \quad 10 - 10^*. \tag{52}$$

The presence of only two independent amplitudes in (52) leads to the appearance of several relations between the constants V and A for different decays of the type (50). Namely,

$$\begin{aligned} V(\Lambda \to n + \gamma) &= -V(\Xi^0 \to \Lambda + \gamma) \\ &= \sqrt{3}V(\Xi^0 \to \Sigma^0 + \gamma), \quad V(\Sigma^+ \to p + \gamma) \\ &= -V(\Xi^- \to \Sigma^- + \gamma), \quad A(\Lambda \to n + \gamma) \\ &= -A(\Xi^0 \to \Lambda + \gamma) = \sqrt{3}A(\Xi^0 \to \Sigma^0 + \gamma), \\ A(\Sigma^+ \to p + \gamma) &= -A(\Xi^- \to \Sigma^- + \gamma), \end{aligned} \tag{53}$$

Inasmuch as the relations for the constants V and A in (53) are the same, the sign of the polarization parameters of the type of the coefficient of asymmetry for all decays in (53) should be the same.

If the notation (49) is valid for hadron decays, then for the baryon current in (51) the condition $\gamma_5 R = -1$ should be replaced by $\gamma_5 RC = -1$. For the constants A, both conditions coincide, and relations (53) again hold for them, whereas for the constants V the baryon current in (51) is now represented by a superposition of the multiplets 8_d and 27, as a result of which the following equalities hold true

$$V(\Lambda\to n+\gamma)=V(\Xi^0\to\Lambda+\gamma)$$
$$=V(\Xi^0\to\Sigma^0+\gamma)/\sqrt{3}, \qquad (54$$
$$V(\Sigma^+\to p+\gamma)=V(\Xi^-\to\Sigma^-+\gamma).$$

Unlike (53), Eq. (54) predicts a different sign for the polarization parameters for decays $\Lambda\to n+\gamma$ and $\Xi^0\to\Lambda+\gamma$, or $\Sigma^+\to p+\gamma$ and $\Xi^-\to\Sigma^-+\gamma$. Comparison of the asymmetry coefficient for such decays therefore makes it possible to establish whether the value of b is the same or different for the two parts of the non-lepton Hamiltonian, and which of the two forms of notation for the matrix element for the hadron decays is preferable. At the present time an experimental verification of relations (53) and (54) is made difficult by the scarcity of available data.

11. CONCLUSION

In this paper we advanced essentially two hypotheses. Namely;

1. Minimal hypothesis. With sufficiently good approximation, $\gamma_5 R$ invariance of strong interactions holds, as a result of which A-parity, defined as $A=\gamma_5 RC$ is conserved.

2. Fundamental hypothesis. There is approximate baroinvariance, that is, strong interactions are degenerate in the baryon charge. This corresponds to the symmetry $SU_3\otimes SU_2$.

As follows from the contents of Secs. 4, 5, 7, 8, and 9, the minimal hypothesis is in good agreement with the experimental data. Only two questions remain unclear—the $\omega-\varphi$ mixing and the two types of decays of the A_2 resonance. It is of interest to check the conservation of A-parity in some new phenomena. It is also desirable to check in addition the relations of Secs. 9 and 10 for amplitudes of hadron and photon decays of hyperons.

As to the fundamental hypothesis, its confirmation would be, first of all, the observation of a pseudoscalar octet in a two-baryon system. More generally, there should exist in the two-baryon system the analogs of all the mesons for which experiment yields $A=-1$. To study the barospin properties of hadrons it is necessary to investigate multibaryon systems with sufficiently large negative strangeness.

A rather natural attempt is to establish a broader group of symmetries, for which the direct product $SU_3\otimes SU_2$ is a subgroup. The simplest possibility would be the SU_6 group. The situation is here perfectly analogous to that considered by Gursey, Radicati, and Sakita [2,3] for a different problem. The assumption that strong interactions are approximately invariant against transformation of such a group is in some sense a maximal hypothesis. Its consequences are discussed in a different paper.

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Note added in proof (March 29, 1965). In a recent communication[47] there is another report of a resonance in the Λn system with S = −1.[47] The following values are reported for its mass and width: $m=(2098\pm 6)$ MeV/c², $\Gamma=(20\pm 15)$ MeV.

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