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Fifth Interaction and Baryon Masses

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We determine the fifth-interaction coupling from large-angle high-energy nucleon-nucleon scattering, and extract the D/F value for baryon matrix elements of a current-current product from hyperon decays. Assuming symmetric-nonet conserved vector current, we predict the baryon octet D/F value. The result fits observations to within 30%. The actual baryon masses fix $\sin\phi \approx \frac{1}{9}-\frac{1}{12}$ for the eighth-component admixture in the fifth-interaction current.

INTRODUCTION

SEVERAL authors[1–4] have suggested that at least part of $SU(3)$ symmetry breaking may be due to the "fifth interaction" described by the Hamiltonian[5]

$$H^V(x) = g_V{}^2 j_\mu{}^V(x) j_\mu{}^{V\dagger}(x), \tag{1}$$

where

$$j_\mu{}^V(x) = \cos\phi\, j_\mu{}^0(x) + \sin\phi\, j_\mu{}^8(x). \tag{2}$$

Since no external weak probe (such as the photon or a lepton pair) coupling to $j_\mu{}^V(x)$ is known, it is quite difficult to verify the existence of this interaction.

However, a particular feature of the interaction—the fact that in the nomenclature of the complex J plane it corresponds to a fixed pole—suggests a possible approach to its isolation. In the elastic scattering of particles with which j_μ couples, the Born term generated by H_V should be dominant for sufficiently large s and t. Here the usual Regge contributions, decaying exponentially in t, are quite negligible. In this region one expects for p-p scattering

$$\lim_{s\to\infty;\, -t\to\infty} \frac{dG}{dt}(s,t) \sim G_{Mp}{}^4(t), \quad \left(\frac{s}{t}\ \text{large}\right) \tag{3}$$

where G_{Mp} is the proton's measured magnetic form factor.[6]

The indication that experimental data may approach the limit of Eq. (3) caused Abarbanel, Drell, and Gilman[7] to suggest that a current×current interaction might be responsible. It has been conjectured by one of us[3,4] that this interaction is identical with the "fifth interaction" H^V of Eq. (1). In this paper we base ourselves on this hypothesis, as well as on the value of $g_V{}^2$ as determined by Abarbanel *et al.*, and on Suzuki and Sugawara's[8] analysis of nonleptonic decays, to compute the mass splittings of baryons.

PROCEDURE

The Born term, derived from an effective $j\times j$ Hamiltonian, was written by Abarbanel *et al.* as follows:

$$T_{NN}{}^V = \bar{g}^2 G^2(t) \bar{u}(p_2{}')\gamma_\mu u(p_2) \bar{u}(p_1{}')\gamma^\mu u(p_1). \tag{4}$$

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[1] M. Gell-Mann and Y. Ne'eman, *The Eightfold Way* (Benjamin, New York, 1969), p. 297.

[2] Y. Ne'eman, Physics 1, 203 (1965).

[3] Reference 1, p. 282.

[4] Y. Ne'eman, *Algebraic Theory of Particle Physics* (Benjamin, New York, 1967), pp. 103–105; Phys. Rev. **172**, 1818 (1968).

[5] Originally a $j_\mu{}^V(x)B^\mu(x)$ interaction was suggested. It is very likely, however, that m_B, the mass of the boson B, is large, so that we can use the effective local form of Eq. (1). [Some lower bounds on m_B have been established by D. Beder, R. Dashen, and S. Frautschi, Phys. Rev. **136B**, 1777 (1964)]. In principle, a large but finite m_B would be indicated if at very large t an additional factor $[m_B{}^2/(t-m_B{}^2)]^2$ would be needed on the right-hand side of Eq. (3).

[6] T. T. Wu and C. N. Yang, Phys. Rev. **137B**, 708 (1965).

[7] H. D. Abarbanel, S. D. Drell, and F. J. Gilman, Phys. Rev. **177**, 2458 (1969).

[8] M. Suzuki, Phys. Rev. Letters **15**, 986 (1965); H. Sugawara, *ibid.* **15**, 870 (1965).

Here the magnetic form factor and helicity flip in general are omitted since t/s is assumed small. The Born term due to H^V of Eq. (1) is, in the same approximation,

$$\begin{aligned}T_{NN}{}^V &= \langle N(p_1')N(p_2')|H^V(x)|N(p_1)N(p_2)\rangle \\ &= \langle N(p_1')N(p_2')|j_0j_0\cos^2\phi+[j_0,j_8]_+\cos\phi\sin\phi \\ &\quad +j_8j_8\sin^2\phi|N(p_1)N(p_2)\rangle \to 3g_V{}^2G^2(t)\bar{u}(p_2') \\ &\quad \times\gamma_\mu u(p_2)\bar{u}(p_1')\gamma^\mu u(p_1) \\ &\qquad \times(\cos^2\phi+\sin\phi\cos\phi+\tfrac{1}{4}\sin^2\phi)\end{aligned} \tag{5}$$

as $s\to\infty$ and $-t\to\infty$ with t/s small. Here, in the last step, we have assumed "symmetric-nonet conserved vector current" (SNCVC), i.e., the equality[9] of the reduced singlet and octet matrix elements in $\langle B|j_\mu|B'\rangle$ within the framework of a generalized CVC. Only then can $G(t)$ of Eq. (5) be identified with the electromagnetic form factor of the nucleon, normalized to $G(0)=1$. It follows now, from Eqs. (4) and (5), that

$$g_V{}^2=\frac{\bar{g}^2}{3}\frac{1}{1+\sin\phi(\cos\phi-\frac{3}{4}\sin\phi)} \tag{6}$$

and, using the determination of Ref. 6,

$$\bar{g}^2/4\pi=5.1\ \mathrm{BeV}^{-2}, \tag{7}$$

we have the required coupling strength $g_V{}^2$.

We now write H^V as

$$\begin{aligned}H^V(x)=g_V\Bigg[s^0(x)\left(\cos\phi-\frac{1}{2\sqrt{2}}\sin^2\phi\right) \\ +s^8(x)\left(2\cos\phi\sin\phi-\frac{1}{\sqrt{5}}\sin^2\phi\right) \\ +0.82\sin^2\phi\, s^{27}(x)\Bigg],\end{aligned} \tag{8}$$

where the s^i transform like the $I=Y=0$ members of the ith $SU(3)$ representation. By including just one s^8 we have implicitly assumed the identity of $\{j_0j_8\}_8$ and $\{j_8j_8\}_8$ parts as implied by SNCVC.

For s^8 we have

$$\langle B_i|s^8|B_j\rangle=Dd_{ij8}+Ff_{8ij}. \tag{9}$$

Let us now write the nonleptonic Hamiltonian in the conventional current×current form with a Cabibbo angle:

$$\begin{aligned}H^{\mathrm{NL}}=\frac{G}{\sqrt{2}}[(j_\mu{}^1+ij_\mu{}^2)\cos\theta_C+(j_\mu{}^4+ij_\mu{}^5)\sin\theta_C] \\ \times[(j_\mu{}^1-ij_\mu{}^2)\cos\theta_C+(j_\mu{}^4-ij_\mu{}^5)\sin\theta_C].\end{aligned} \tag{10}$$

The Suzuki-Sugawara analysis of S-wave hyperon decays then yields[10]

$$\langle B_i|H^{\mathrm{NL}}|B_j\rangle=(2D^wd_{6ij}+2F^wf_{6ij})\bar{u}_iu_j, \tag{11}$$

where

$$\begin{pmatrix}D^w\\F^w\end{pmatrix}\cong2\times\begin{pmatrix}1.6\\3.6\end{pmatrix}\times10^{-5}\ \mathrm{MeV}$$

are the reduced matrix elements of the parity-conserving part of H^{NL} between the baryons. In order to be able to compare the F's of Eqs. (9) and (11), we now make our final assumption[11]:

$$\langle B|\{j_\mu{}^i(x)j_\mu{}^j(x)\}|B\rangle=\langle B|\{j_\mu{}^{5i}(x)j_\mu{}^{5j}(x)\}_8|B\rangle. \tag{12}$$

Combining Eqs. (12), (11), and (9), we have, after collecting all factors,

$$\begin{aligned}\begin{pmatrix}D\\F\end{pmatrix}&=\begin{pmatrix}D^w\\F^w\end{pmatrix}\frac{0.88\sqrt{2}}{10^{-5}(\sin\theta_C\cos\theta_C)\times2(\frac{3}{10}\sqrt{5})\sqrt{\frac{2}{3}}} \\ &\simeq\begin{pmatrix}9\\-20\end{pmatrix}\mathrm{MeV}\times2=\begin{pmatrix}18\\-40\end{pmatrix}\mathrm{MeV}.\end{aligned} \tag{13}$$

Hence the contribution of s^8 to the octet mass formula is

$$\begin{aligned}g^2s^8\left(2\cos\phi\sin\phi-\frac{1}{\sqrt{5}}\sin^2\phi\right)\begin{pmatrix}D\\F\end{pmatrix} \\ \simeq\begin{pmatrix}64\\-140\end{pmatrix}\left[13\frac{\cos\phi\sin\phi}{1+\sin\phi(\cos\phi-\frac{3}{4}\sin\phi)}\right].\end{aligned} \tag{14}$$

These values are to be compared with the D/F parts of the Gell-Mann–Okubo baryon mass formula,

$$\begin{pmatrix}D\\F\end{pmatrix}\simeq\begin{pmatrix}65.7\\-220\end{pmatrix}\mathrm{MeV}.$$

We note first that the relation $D/F\sim D^w/F^w$, which follows from our previous assumptions and which is independent of the specific values of g^V or ϕ, holds to within $\approx30\%$.[12] In order to fit the actual scale of D/F we have to choose from Eq. (13), $\sin\phi\approx\frac{1}{9}$–$\frac{1}{12}$. This leads to two consequences: (a) a relatively small ($\sin^2\phi\sim10^{-2}$) s^{27} part in baryon mass splittings, without having to rely on strong octet dynamical enhancement, and (b) a very large singlet part s^0, as compared with s^8. This

[9] Such a nonet structure is evident in the vector mesons which are related to the currents via the field current identities or simple vector-dominance-model schemes, and is also suggested by the quark duality diagrams.

[10] Y. Hara, Phys. Rev. Letters 16, 380 (1966); Progr. Theoret. Phys. (Kyoto) 37, 710 (1967).

[11] In principle this assumption could be checked by a direct computation of the $j_\mu{}^5j_\mu{}^5$ and $j_\mu j_\mu$ contributions [e.g., S. Nussinov and G. Preparata, Phys. Rev. 175, 2180 (1968)]. Alternatively this assumption might be justified by asymptotic chiral symmetry [T. Das, S. Okubo, and V. S. Mathur, Phys. Rev. Letters 18, 761 (1967)]. Asymptotic chiral symmetry seems to be particularly appropriate, since the singular product $j(x)j(x)$ is involved here.

[12] This fact has been known for some time. Attempts to explain it by postulating that the Hamiltonian of $SU(3)$-breaking and parity-conserving NL interactions belong to the same octet of $u_i(x)$ [$u_i(x)\sim\bar{\phi}(x)\lambda_i\phi(x)$ in quark models] have failed because the nonleptonic Hamiltonian could then be rotated away.

leads to the interesting possibility that the majority of the common baryon mass comes from this source. In particular, in keeping with our nonet structure assumption, if we now assume that $\langle B|s^0|B\rangle$ is related to $\langle B|s^8|B\rangle_D$ by the generalized d coefficient, we find $\langle B_i|s^0|B_j\rangle\sim\delta_{ij}\times 400$ MeV, so that the j^0j^0 part of our model Eq. (1) (which is equivalent to a gluon model with a large gluon mass) could constitute the $SU(3)\times SU(3)$-invariant part of the Hamiltonian. Note that the invariant part should, according to recent calculations, produce the major part of the baryon masses.[13]

Summing up, we should emphasize that our conclusions depend on several assumptions, as stated above, as well as on the $g_V{}^2$ determination by Abarbanel *et al.* [Eq. (7)]. It is our belief that the result obtained here, pointing out the importance of H^V of Eq. (1) in fixing the hadron spectrum, might be correct and should be further investigated.

[13] A recent estimate [J. K. Kim and F. von Hippel, Phys. Rev. Letters **22**, 740 (1969)] done in the framework of the Gell-Mann–Oakes–Renner model [Phys. Rev. **175**, 2195 (1968)] for $SU(3)\times SU(3)$ breaking has indicated that the $SU(3)\times SU(3)$-violating Hamiltonian accounts only for a small portion ($\approx$170 MeV) of the common mass of the baryon octet.

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Nishijima's Model with a Fifth Interaction

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Nishijima's model for CP violation introduces a divergencelike term in the strong Hamiltonian and attributes the nonleptonic weak interaction to the second-order contribution due to that term (CP violation arises in third order). By using a unitary scalar density plus the fifth interaction for the original strong Hamiltonian, we induce in Nishijima's weak Hamiltonian a current-current structure, somewhat similar to the conventional one. Moreover, it becomes equivalent to tadpole terms for $|\Delta S|=1$. The $\Delta S=0$ weak transitions are somewhat modified. We get the correct $|\Delta I|=\frac{3}{2}$ admixture from a counter term which relegates the $|\Delta S|=2$ contributions to fourth order (i.e., second-order weak interactions). We find $|\eta_{00}|\sim|\eta_{+-}|$ to within 10%.

INTRODUCTION

In the preceding article[1] we investigated the possibility that the "fifth interaction" represented by the Hamiltonian

$$H^V(x)=g_V{}^2 j_\mu{}^V(x) j^{\mu V}(x)\,,$$

with (1)

$$j_V{}^\mu(x)=j_0{}^\mu(x)\cos\phi_V+j_8{}^\mu(x)\sin\phi_V\,,$$

describes the strong interactions, including the breaking of $SU(3)$, for the baryon octet $(\frac{1}{2})^+$. We checked consistency with the elastic scattering amplitudes for baryons, and with the nonleptonic decay amplitudes of hyperons.

We used the strong assumption of symmetric-nonet conserved vector current (SNCVC), equating the reduced matrix elements of $j_0{}^\mu j_{\mu 8}$ and $j_{i\mu}j_l{}^\mu$ [i, $1=1\cdots 8$, according to Gell-Mann's notation for the $SU(3)$ octet components]. However, the resulting difference between D^w/F^w and D^s/F^s [the ratios in nonleptonic parity-violating decays of hyperons, and in the $SU(3)$-breaking part of the Hamiltonian describing the baryon octet masses, respectively] has yet to be accounted for.

In this paper we construct an explicit Hamiltonian for nonleptonic weak interactions, using the Nishijima model.[2] We thus investigate the possibility of a universal D/F and the correlation between the fifth-interaction parameters and the nonleptonic decays.

NISHIJIMA MODEL

Nishijima has suggested adding to $H_0(x)$, which is the Hamiltonian describing the strong and semistrong

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† Supported in part by the U. S. Air Force Office of Scientific Research, Office of Aerospace Research, under AFOSR Grant No. EOOAR-68-0010, through the European Office of Aerospace Research.
[1] Y. Ne'eman, S. Nussinov, and A. Schorr, Phys. Rev. D **1**, 229 (1970).

[2] K. Nishijima, Progr. Theoret. Phys. (Kyoto) **41**, 739 (1969).