Watanabe.[7] It should be noted, however, that some variants of their theory may be found which cannot be disproved by one negative experiment alone. Therefore, it is desirable that both of these experiments be performed. It seems to be rather difficult to invent a theory of the Tanikawa type which does not give a resonance in any of the processes $\nu+p$, $\nu+n$, $e+p$, and $e+n$, where ν and e denote either particles or antiparticles.

We conclude that it is probably worthwhile to search for possible anomalies in electron and neutrino reactions over the energy range which may be covered with the present accelerators before looking into weak processes at higher energies.

I should like to thank C. R. Schumacher for checking some of the calculations.

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[1] R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958); E. C. G. Sudarshan and R. E. Marshak, Phys. Rev. 109, 1860 (1958).

[2] M. Schwartz, Phys. Rev. Letters 4, 360 (1960); T. D. Lee and C. N. Yang, Phys. Rev. Letters 4, 307 (1960). Similar considerations have recently been made by Y. Yamaguchi (to be published), and N. Cabbibo and R. Gatto (to be published).

[3] It is usually assumed that neutrinos emitted in the $\pi-\mu$ decay and β decay are of the same kind. There is no positive proof for this, however. Obviously, it is desirable that this be examined experimentally.

[4] The possibility that weak interactions are mediated by a boson has been considered by many authors: H. Yukawa, Proc. Phys.-Math. Soc. Japan 17, 48 (1935); J. Schwinger, Ann. Phys. 2, 407 (1957); T. D. Lee and C. N. Yang, Phys. Rev. 108, 1611 (1957); R. P. Feynman and M. Gell-Mann, Phys. Rev. 109, 193 (1958); Y. Tanikawa, Progr. Theoret. Phys. (Kyoto) 3, 338 (1948); Y. Tanikawa and S. Watanabe, Phys. Rev. 113, 1344 (1959).

[5] S. L. Glashow, Phys. Rev. (to be published).

[6] Lee and Yang (reference 2) showed that the production cross section of such a boson in the neutrino-nucleus collision is about 10^{-35} cm^2 for an incident neutrino energy much greater than 2 Bev. This is more practical than the resonance scattering method as a direct test of the intermediate boson hypothesis. It should be noted that the absence of $\mu\to e+\gamma$ is not conclusive evidence against the intermediate-boson hypothesis. See G. Feinberg, Phys. Rev. 110, 1482 (1958).

[7] Y. Tanikawa and S. Watanabe, Phys. Rev. 113, 1344 (1959).

[8] The theory of Tanikawa and Watanabe leads to the $V-A$ theory only after spinors are rearranged by the Fierz transformation. In this theory, therefore, it is not easy (if not impossible) to find a natural explanation for the conservation of the vector current part of the weak interaction, if it is in fact conserved (R. P. Feynman and M. Gell-Mann, reference 1). If the presence of the weak magnetism [M. Gell-Mann, Phys. Rev. 111, 362 (1958)] is established experimentally, it may again be hard to explain by Tanikawa's theory. The experimental result is not conclusive yet.

[9] In this case, formulas (8) and (10) must be modified slightly to take account of an additional decay mode of the B particle.

[10] R. Hofstadter, F. Bumiller, and M. R. Yearian, Revs. Modern Phys. 30, 482 (1958).

AXIAL VECTOR CURRENT CONSERVATION IN WEAK INTERACTIONS[*]

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In analogy to the conserved vector current interaction in the beta decay suggested by Feynman and Gell-Mann, some speculations have been made about a possible conserved axial vector current.[1-3] One can formally construct an axial vector nucleon current, which satisfies a continuity equation,

$$\Gamma_\mu^A(p',p)=i\gamma_5\gamma_\mu-2M\gamma_5 q_\mu/q^2,\quad q=p'-p, \qquad (1)$$

where p and p' are the initial and final nucleon momenta. Such an attempt has some appeal in view of the apparently modest renormalization effect on the axial vector beta decay constant ($g_A/g_V\approx 1.25$), although the second appealing point,[1] namely, the possible forbidding of $\pi\to e+\nu$, has now lost its relevance.

The expression (1), unfortunately, can be easily ruled out experimentally, as was pointed out by Goldberger and Treiman,[3] since it introduces a large admixture of pseudoscalar interaction.

On the other hand, Eq. (1) arouses theoretical curiosity as to the origin of the second term if it really exists; according to our conventional field theory, we would have to interpret the denominator q^2 as implying a massless, pseudoscalar, and charged quantum bridging the nucleon and lepton currents.

We would like to suggest that there may not be a strict pseudovector current conservation, but that we may have an approximate conservation which becomes rigorous in the limit $q^2 >> m_\pi^2$, m_π being the pion mass. Specifically, we propose that the axial vector part of the nucleon beta decay vertex has the following form and properties:

$$g_A\Gamma_\mu^A(p',p)$$
$$= g_V\left[i\gamma_5\gamma_\mu F_1(q^2) - \frac{2M\gamma_5 q_\mu}{q^2+m_\pi^2}F_2(q^2)\right],$$
$$F_1(0) = g_A/g_V \approx F_2(0);$$
$$F_1(q^2) \sim F_2(q^2) \quad \text{for} \quad q^2 >> m_\pi^2. \qquad (2)$$

The pion is then the analog of the massless quantum mentioned above. This is consistent with the dispersion relations expected for Γ_μ^A. Namely, F_1 and F_2 should have in general the form

$$F_i(q^2) = F_i(-m_\pi^2)$$
$$-(q^2+m_\pi^2)\int_{m_0^2}^{\infty}\frac{\rho_i(m^2)dm^2}{(q^2+m^2)(m^2-m_\pi^2)}$$
$$(i=1,2), \qquad (3)$$

where $m_0 = 3m_\pi$ unless there are new particles of low mass. Thus the F's will be slowly varying for $|q^2| << m_0^2$. The conditions in Eq. (2) imply that $F_1/F_2 \approx 1$ for all q^2. If $m_\pi = 0$ and $F_1/F_2 \equiv 1$, then we restore exact current conservation,[2] and we also expect $F_1(0) = g_A/g_V = 1$.

If we adopt Eq. (2), the second term of Γ_μ^A immediately gives a relation between g_A, the pion decay (pseudovector) constant g_π, and the pion-nucleon (pseudoscalar) coupling G_π:

$$2Mg_A \approx 2Mg_V F_2(-m_\pi^2) = \sqrt{2}\,G_\pi g_\pi. \qquad (4)$$

With $g_A = 1.25\,g_V = 1.75\times10^{-49}$ erg cm^3,[4] $G_\pi^2/4\pi = 13.5$, this gives a π-μ decay life of 2.7×10^{-8} sec as compared with the observed value 2.56×10^{-8} sec.

Goldberger and Treiman[5] have arrived at the same relation Eq. (4) (in the limit of their self-energy integral $J\to\infty$) from an entirely different approach. In our opinion, this is not a coincidence, as will be explained elsewhere.

We are tempted to extend this approximate conservation of the axial vector (and naturally also the vector current) to the strangeness-nonconserving beta decays. We take, for example, the ΛN axial vector in the form

$$\Gamma_\mu^A(p_N', P_\Lambda) \approx i\gamma_5\gamma_\mu - \frac{(M_\Lambda+M_N)\gamma_5 q_\mu}{q^2+m_K^2}, \qquad (5)$$

and attribute the second term to the pseudoscalar K meson.[6] The degree of accuracy of the relation (5) will be poorer than in the previous case in view of the Λ-N mass difference (which destroys vector conservation) and the large K-meson mass. At any rate, we obtain an analog of Eq. (4):

$$(M_\Lambda+M_N)g_A' \approx G_K g_K, \qquad (6)$$

which relates the Λ beta decay axial vector coupling g_A', the ΛNK coupling G_K, and the K_μ decay coupling g_K.

With the observed $K_{\mu 2}$ lifetime 2.1×10^{-8} sec and a tentative value $G_K^2/4\pi = \frac{1}{4}G_\pi^2/4\pi$, we get

$$g_A'/g_A \approx 1/10. \qquad (7)$$

This is not inconsistent with the observed beta decay of Λ which seems an order of magnitude less than predicted from a universal coupling scheme $g_V' = g_A' = g_V$.[7]

We can still go further, though the argument becomes more arbitrary. Let us assume that a fundamental weak coupling $(\bar N N \bar N \Lambda)$ gives rise to an effective V-A interaction (or at least part of it) of the form

$$g''(\Gamma_\mu^V - \Gamma_\mu^A)_{\bar N N}(\Gamma_\mu^V - \Gamma_\mu^A)_{\bar N \Lambda}. \qquad (8)$$

Here $\Gamma_\mu^V = i\gamma_\mu$ which is approximately conserved by itself, and Γ_μ^A stands for Eq. (2) or (5). We see easily that Eq. (8) contains information about the $\Lambda\to N+\pi$ decay matrix element:

$$(2M_N g''/\sqrt{2}\,G_\pi)q_\mu(\Gamma_\mu^V - \Gamma_\mu^A)_{\bar N\Lambda}. \qquad (9)$$

Combined with the assumption of $\Delta T = \frac{1}{2}$ selection rule, this gives a lifetime of 2.5×10^{-10} sec for $g''=g_V$ as compared with the observed value 2.8×10^{-10} sec.

It is possible to apply this kind of consideration to other hyperons. Moreover, if the Feynman–Gell-Mann coupling scheme such as $(\pi\pi e\nu)$ is formally extended to $(K\pi e\nu)$, etc. as has been tried by some people, all the observed decay processes may be covered. Here we would like to point out that if all baryons should satisfy Eqs. (4) and (6), the ratios g_A/G_π and g_A'/G_K must be approximately common constants.

Our final remark concerns the theoretical basis for the assumptions made here. If the baryons are derived from some fundamental field ψ which possesses an invariance under a transformation of the type $\psi\rightarrow\exp(i\vec{\alpha}\cdot\vec{\tau}\gamma_5)\psi$,[8] then there will be a conservation of the pseudovector charge-current. A finite observed mass can be compatible with the conservation if the particle is coupled with a boson as was noted in Eq. (1).

This situation may be understood by making an analogy to the theory of superconductivity originated by Bardeen, Cooper, and Schrieffer,[9] and refined by Bogoliubov.[10] There gauge invariance, the energy gap, and the collective excitations are logically related to each other as was shown by the author.[11] In the present case we have only to replace them by γ_5 invariance, baryon mass, and the mesons. In fact, the mathematical method used in superconductivity may be taken over to study the self-energy problem of elementary particles. It is interesting that pseudoscalar mesons automatically emerge in this theory as bound states of baryon pairs. The nonzero meson masses and baryon mass splitting would indicate that the γ_5 invariance of the bare baryon field is not rigorous, possibly because of a small bare mass of the order of the pion mass.

The above-mentioned model of elementary particles will be studied in a separate paper.

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[*] This work was supported by the U. S. Atomic Energy Commission.

[1] J. C. Taylor, Phys. Rev. 110, 1216 (1958).

[2] J. C. Polkinghorne, Nuovo cimento 8, 179 and 781 (1958).

[3] M. L. Goldberger and S. B. Treiman, Phys. Rev. 110, 1478 (1958).

[4] A. I. Alikhanov, Ninth Annual International Conference on High-Energy Physics, Kiev, 1959 (unpublished).

[5] M. L. Goldberger and S. B. Treiman, Phys. Rev. 110, 1178 (1958); M. L. Goldberger, Revs. Modern Phys. 31, 797 (1959).

[6] It is also possible to associate a scalar K meson with the ΛN vector current conservation, while leaving the axial vector unaccounted for.

[7] Again Eq. (5) and the subsequent conclusions are essentially the same as those of C. H. Albright, Phys. Rev. 114, 1648 (1959) and B. Sakita, Phys. Rev. 114, 1650 (1959), which are based on the Goldberger-Treiman method. For the Λ-decay case below, see L. Tenaglia, Nuovo cimento 14, 499 (1959).

[8] F. Gürsey (private communication) has recently obtained similar results on the π decay based on this γ_5 invariance. We do not here specify the interaction of the ψ field, which may be of the nonlinear Heisenberg type, or due to an intermediate boson (different from π or K).

[9] J. Bardeen, L. N. Cooper, and J. R. Schrieffer, Phys. Rev. 106, 162 (1957).

[10] N. N. Bogoliubov, V. V. Tolmachev, and D. V. Shirkov, A New Method in the Theory of Superconductivity (Academy of Sciences of USSR, Moscow, 1958).

[11] Y. Nambu, Phys. Rev. 117, 648 (1960).

ERRATUM

HELICITY OF NEGATIVE MUONS FROM PION DECAY. W. A. Love, S. Marder, I. Nadelhaft, and R. T. Siegel [Phys. Rev. Letters 2, 107 (1959)].

In this Letter we presented preliminary results of an experiment designed to measure the forward-backward asymmetry of β rays emitted from B^{12}, which has been produced by absorption of polarized muons in carbon (in C_5H_{12}). Continuing measurements have yielded an amended result for the asymmetry parameter a, as defined in this Letter, of $a=(0.64\pm0.58)\%$. It thus appears that in pentane the B^{12} is depolarized by one of the various interactions (quadrupole coupling, multiple electron capture and loss, etc.) which might cause spin reorientation. Therefore, a definite conclusion about the helicity of the negative muon cannot be drawn from our results to date.