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We study the possibility that some of the intermediate vector bosons of the intermediate vector bosons of the weak interaction might be produced by several orders of magnitude more than previously estimated in various literatures.[1]

The intermediate vector bosons, W, if they exist at all, interact with the strangeness nonchanging baryon current $J_\mu^B(\Delta S = 0)$, the strangeness changing baryon current $J_\mu^B(\Delta S = +1)$, and the lepton current $J_\mu(\text{lep})$.[2] Let us call the respective coupling constants g_0, g_1, and g_{Lep}. If there exists more than one kind of intermediate boson besides its charge multiplets, the coupling constants may be different for the different kinds of bosons.

The circumstances which could give rise to copious productions of the intermediate bosons are the following:

(I) The nonleptonic and leptonic decays of baryons and K mesons are mediated by two different kinds of vector bosons, which we shall call the nonleptonic boson W_N and leptonic boson W_L respectively. (We assume that (a) the weak interaction currents are derived from the invariance under a set of gauge transformations, and (b) the transformations form a simple Lie group; then we find the leptonic currents and nonleptonic currents do not seem to be constructed if we use the same representation of the Lie group in order to explain the known experimental results. Therefore, under these assumptions, more than one kind of boson is required.[3])

(II) The magnitudes of g_0 and g_1 for W_L are different in order of magnitudes. (Any known universality of a group of coupling constants in the elementary-particle physics is connected with the invariance of the relevant interactions under a certain group of gauge transformations. For example, the universality of the pion-nucleon coupling constants for differently charged pions is derived from the invariance under the isotopic-spin gauge transformations. And the 2 x 2 representations of the group (with a dimension 3) give explicitly the equality of the three coupling constants between the $\pi_{1,2,3}$ and nucleons $[\pi_1 = (\pi_+ + \pi_-)/\sqrt{2},\ \pi_2 = -i\ (\pi_+ - \pi_-)/\sqrt{2},\ \pi_3 = \pi_0]$. In general, however, an n x n representation of a Lie group with a dimension m can contain a certain number of real parameters if n is large enough. Therefore, if the currents of weak interactions are constructed by using such a representation of the relevant group, values of two constants such as g_0 and g_1 can be different in order of magnitudes.[3, 4]) Under the assumption (I) the weak interaction Lagrangian can be written as follows:

$$\mathcal{L} = \mathcal{L}_N + \mathcal{L}_L , \tag{1}$$

$$\mathcal{L}_N = g_0 (W_N)_\mu \cdot J_\mu (\Delta S = 0) + g_1 (W_N)_\mu \cdot J_\mu (\Delta S = +1)$$

$$+ \text{ hermitian conjugates,}$$

$$\mathcal{L}_L = g_0 (W_L)_\mu \cdot J_\mu (\Delta S = 0) + g_1 (W_L)_\mu \cdot J_\mu (\Delta S = +1)$$

$$+ g_{Lep} (W_L)_\mu \cdot J_\mu (\text{lep}) + \text{ hermitian conjugates.}$$

Here the values of the coupling constants g_0 and g_1, and the explicit forms of the baryon currents are different for $\mathcal{L}_N$ and $\mathcal{L}_L$. We have suppressed the notations corresponding to various charge multiplets of W and J for simplicity, although they are implied in Eq. (1).

Our present experimental knowledge on the magnitudes of g is summerized as follows:[1]

From the rates of the nonleptonic hyperon decays, we obtain

$$(g_0\, g_1)^2 \approx 10^{-13} \quad \text{for} \quad W_N \quad . \tag{2}$$

From the rates of the β-decay of nucleons, the μ-e decay, and the leptonic decays of hyperons we obtain[5]

$$(g_0\, g_{\text{Lep}})^2 \approx 10^{-13}, \quad ({g_{\text{Lep}}}^2)^2 \approx 10^{-13}, \quad (g_1\, g_{\text{Lep}})^2 \lesssim 10^{-13} \quad \text{for} \quad W_L \quad . \tag{3}$$

We now ask if there is a possibility that such a W_N has been already found? It is important only that we know the magnitude of the product $g_0\, g_1$ but not g_0 and g_1 separately for W_N. While for W_L we obtain the near universality of the coupling constants

$${g_0}^2 \approx {g_{\text{Lep}}}^2 \gtrsim {g_1}^2 \quad . \tag{4}$$

Cross sections for W productions by collisions between two strongly interacting particles are estimated to be smaller than cross sections for usual reactions by a factor of $\approx 10^{-13/2}$. However, if $g_0 \gg g_1$ or $g_1 \gg g_0$ for W_N, this factor becomes ${g_0}^2$ or ${g_1}^2$ instead of $10^{-13/2}$ and a large W_N-production cross section is expected.

Because of $g_{\text{Lep}} = 0$ for W_N, W_N decays exclusively into several strongly interacting particles but not into leptons. If $g_0 \gg g_1$, W_N decays mostly into a system of particles with the total strangeness $S = 0$ such as

2π and $K\bar{K}$ and will be found as a sharp resonance in the $\pi - \pi$ or $K - \bar{K}$ scatterings. On the other hand, if $g_1 \gg g_0$ W_N decays mostly into a system with $S = \pm 1$, such as a πK or $\pi\bar{K}$, and will be found as a sharp resonance in the πK or $\pi\bar{K}$ scatterings. In both cases the resonance must appear in a $J = 1$ state.

Difficulty in identifying such a resonance as the W_N is two-fold. First, the strangeness is conserved to a very good extent in the over-all processes (W_N production and its subsequent decay). The degree of violation of strangeness conservation is only of an order of g_1^2/g_0^2 or g_0^2/g_1^2 depending on whether $g_0 \gg g_1$ or $g_1 \gg g_0$. Second, the parity nonconservation in the decay of W_N cannot be observed in its main decay processes going into two spin-0 particles such as 2π, πK, and $K\bar{K}$. Thus one has to look for the parity nonconservation in less frequent decays of W_N going into more than two particles.

Presumably one of the easiest ways to identify a resonance as the W_N is to look for the parity nonconservation in the production processes of W_N. For example, one can measure a polarization of a particle such as Λ in its production plane, when it is produced together with the resonance. And a nonvanishing polarization[6] of Λ would prove the resonance is the W_N.

If either g_0^2 or g_1^2 is large and much larger than $10^{-13/2}$, this will lead to parity nonconservation in any strong interaction processes, because the same processes can proceed through the weak interaction with appreciable amplitudes. If $g_0 \gg g_1$, parity would be strongly violated in processes not involving strange particles. On the other hand, if $g_1 \gg g_0$, violations would show up strongly in processes involving strange particles. Present experimental evidence for parity conservation[7] in strong interactions could give us upper limits on the magnitudes of g_0 and g_1. Although it is hard to make an accurate estimate of them, we shall tentatively put the limits as follows:

$$g_0^2 \lesssim 10^{-2} \text{ and } g_1^2 \lesssim 10^{-1} \text{ for } W_N \quad . \tag{5}$$

Unless the value of either g_0^2 or g_1^2 is near the foregoing upper limit, the production cross section of W_N is still small and it will be hard to find the resonance corresponding to the W_N. A possible candidate for W_N is, for example, the reported $K\pi$ resonance with a mass 730 MeV and a narrow width ($\Gamma < 20$ MeV).[8] We shall call this resonance K_N^*. If it turns out to be a real resonance with $J = 1$, it could be the W_N intermediating the nonleptonic weak interactions. Furthermore, if one observes a nonvanishing polarization of Λ (or Σ) in its production plane when it is produced with a K_N^*, this would strongly suggest K_N^* is the W_N.

A rough estimate of the ratio R of K_N^* production cross sections to that of K^* in various experiments is $R \lesssim 10^{-1}$. Theoretically R would not be very far from the ratio of the K_N^* width to the K^* width (≈ 50 MeV). If we express the $K_N^* K\pi$ coupling by the following Lagrangian,[9]

$$\mathcal{L} = (4\pi)^{1/2} g_1 (K_N^*)_\mu K \partial_\mu \pi + \text{hermitian conjugates} , \tag{6}$$

the width for $K_N^* \to K + \pi$ decay is given by

$$\Gamma(K_N^*) = g_1^2 (4q^3/3M^2) \quad . \tag{7}$$

Here q is the momentum of K (or π) in the K_N^* rest system and M is the K_N^* mass (≈ 730 MeV). Thus we obtain the following value of R,

$$R \approx g_1{}^2(4q^3/3M^2)\ (50\ \text{MeV})^{-1} \approx \frac{1}{5} \times g_1{}^2 \quad . \tag{8}$$

From $R \lesssim 10^{-1}$ and Eq. (8), we obtain

$$g_1{}^2 \lesssim 0.5\ (g_0{}^2 \gtrsim 2 \times 10^{-13}) \quad . \tag{9}$$

This value of $g_1{}^2$ is barely consistent with Eq. (5).

Because of $g_1{}^2 \gg g_0{}^2$, K_N^* decays mostly into a $K + \pi$ and with much less probability ($\approx g_0{}^2/g_1{}^2 \approx 4 \times 10^{-11}$) into 2π, 3π, and so on. Therefore, the chance for this W_N to be observed as a $\pi - \pi$ resonance is very small.

Another candidate for W_N is the reported $\zeta^{\pm,0}$ with a mass ≈ 560 MeV and a narrow width ($\Gamma < 15$ MeV).[10] In this case we must have $g_0{}^2 \gg g_1{}^2$, and the W_N decays mostly into 2π (it cannot decay into a $K + \pi$ because of its small mass). However, the condition $g_0{}^2 \lesssim 10^{-2}$ [Eq. (5)] may be hard to reconcile with this possibility.

Although no established $J = 1$ resonance with such a small width as to satisfy Eq. (5) is known at present, it should be re-emphasized that possible values for $g_0{}^2$ and $g_1{}^2$ have the large range given by Eqs. (2) and (5) and the W_N can be produced much more copiously than previously expected.

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REFERENCES AND FOOTNOTES

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[†] On leave of absence from Physics Department, Tohoku University, Sendai, Japan.

1. T. D. Lee and C. N. Yang, Phys. Rev. 119, 1410 (1960).

2. The lepton current can also be divided into two parts; however, this is irrelevant for our discussions.

3. Gyo Takeda, Ann. Phys. 18, 310 (1962).

4. A. Pais, Phys. Rev. Letters 6, 291 (1961).

5. The observed small leptonic decay rates of hyperons suggest $g_1^2 \lesssim 0.1 \times g_0^2$.

6. The expected magnitude of polarization should be independent of the magnitude of g_0^2 (or g_1^2) and could be very large.

7. T. D. Lee and C. N. Yang, Elementary Particles and Weak Interactions, Brookhaven National Laboratory, (1957) p. 16, and F. S. Crawford, 1962 International Conference on High Energy Physics, CERN, p. 270.

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9. Here we neglect complications resulting from the existence of more than one different charge decay mode.

10. R. Barloutond, J. Henghebaert, A. Leveque, J. Meyer, and R. Omnes, Phys. Rev. Letters 8, 32 (1962).