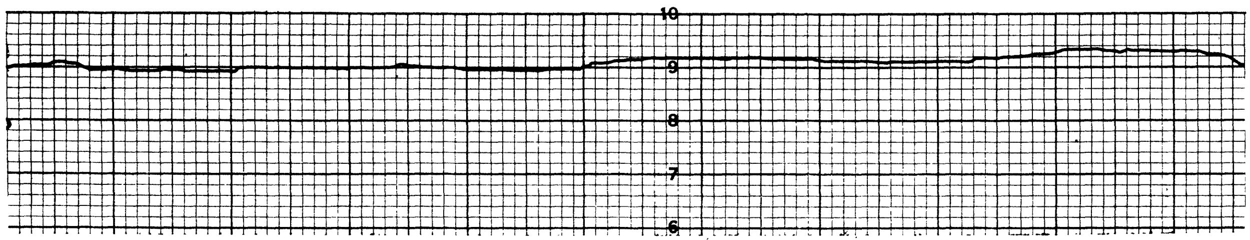

FIG. 3. Drift during two minutes of the beat frequency between two masers. One small division represents 4 kilocycles per second change.

or optical maser is the precision with which an individual maser can be reset to the same frequency after its frequency has been disturbed. In principle, there is no limit to the precision of resettability if sufficient time is taken for the purpose, and even for rather short times the limit to accuracy of resetting determined by fundamental noise is very high. However, many practical problems prevent any immediate approach to this limit. For the purpose of resettability measurements, two masers were kept at single mode operation and were adjusted very close to the threshold of oscillation. The frequency of each maser was then reset by varying the mirror separation until the oscillation disappeared and then setting the separation half-way between the two points of disappearance. On each trial, resetting the resulting beat frequency between the two was measured. Its variation among a number of trials was about 500 kc/sec. This shows that a single maser can be reset to a precision at least as good as one part in 10^9, and hence distances compared over a very long time to this accuracy. In this experiment the mirror separation was varied by magnetostrictive effects in the separators. It is believed that further work can much improve the long-term stability and resettability of optical masers, although they are already sufficiently good for many interesting measurements of length.

An experiment to detect "ether drift" or anisotropy in the velocity of light of the Michelson-Morley type previously outlined[4] is being carried out to capitalize on the precision in measurement of length indicated above. The first version of such an experiment can be considered to confirm the Lorentz-Fitzgerald contraction due to the earth's orbital velocity to about one part in one thousand. This work will be separately reported in more detail.

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[1]A. Javan, E. A. Ballik, and W. L. Bond, J. Opt. Soc. Am. 52, 96 (1962).

[2]T. S. Jaseja, A. Javan, J. Murray, and C. H. Townes, Bull. Am. Phys. Soc. 7, 553 (1962).

[3]A. L. Schawlow and C. H. Townes, Phys. Rev. 112, 1940 (1958).

[4]C. H. Townes, Advances in Quantum Electronics, edited by J. R. Singer (Columbia University Press, New York, 1961), p. 3.

POSSIBILITY FOR COPIOUS PRODUCTION OF THE INTERMEDIATE VECTOR BOSONS*

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We study the possibility that some of the intermediate vector bosons of the weak interaction might be produced by several orders of magnitude more than previously estimated in various literature.[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 $J_\mu(\mathrm{lep})$.[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 orders of magnitude. {Any known universality of a group of coupling constants in 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 2×2 representations of the group (with dimension 3) give explicitly the equality of the three coupling constants between $\pi_{1,2,3}$ and nucleons [$\pi_1=(\pi_++\pi_-)/\sqrt{2}$, $\pi_2=-i(\pi_+-\pi_-)/\sqrt{2}$, $\pi_3=\pi_0$]. In general, however, an $n\times n$ representation of a Lie group with 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 orders of magnitude.[3,4]} Under the assumption (I) the weak interaction Lagrangian can be written as follows:

$$\mathfrak{L}=\mathfrak{L}_N+\mathfrak{L}_L,$$

$$\mathfrak{L}_N=g_0(W_N)_\mu J_\mu(\Delta S=0)+g_1(W_N)_\mu J_\mu(\Delta S=+1)$$
$$+\text{ Hermitian conjugates},$$
$$\mathfrak{L}_L=g_0(W_L)_\mu J_\mu(\Delta S=0)+g_1(W_L)_\mu J_\mu(\Delta S=+1)$$
$$+g_{\text{lep}}(W_L)_\mu J_\mu(\text{lep})+\text{Hermitian conjugates}. \tag{1}$$

Here the values of the coupling constants g_0 and g_1, and the explicit forms of the baryon currents are different for $\mathfrak{L}_N$ and $\mathfrak{L}_L$. 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 summarized as follows[1]: From the rates of the nonleptonic hyperon decays, we obtain

$$(g_0g_1)^2\approx10^{-13} \text{ for } W_N. \tag{2}$$

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

$$(g_0g_{\text{lep}})^2\approx10^{-13},$$

$$(g_{\text{lep}}^2)^2\approx10^{-13},$$

$$(g_1g_{\text{lep}})^2\lesssim10^{-13} \text{ for } W_L. \tag{3}$$

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_0g_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

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

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 $\approx10^{-13/2}$. 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 π-π or K-$\bar{K}$ scatterings. On the other hand, if $g_1\gg g_0$, W_N decays mostly into a system with $S=\pm1$, 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 twofold. 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 order 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. 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:

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

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 mediating 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

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

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:

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

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

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

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 π - π 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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[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. (N.Y.) 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 Report No. 443, 1957 (unpublished), p. 16; F. S. Crawford, International Conference on High-Energy Nuclear Physics, Geneva, 1962 (CERN Scientific Information Service, Geneva, Switzerland, 1962), p. 270.

[8]G. Alexander, G. R. Kalbfleisch, D. H. Miller, and G. A. Smith, Phys. Rev. Letters 8, 447 (1962).

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

[10]R. Barloutaud, J. Henghebaert, A. Leveque, J. Meyer, and R. Omnès, Phys. Rev. Letters 8, 32 (1962).

PION RESONANCES, REGGE POLES, AND THE CHEW-FRAUTSCHI SATURATION PRINCIPLE

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In two previous papers,[1] hereafter referred to as I and II, respectivly, self-consistent calculations were made for the $I=1, l=1$ and $I=0, l=2$ resonances in low-energy π - π scattering. These did not entail any phenomenological parameters. Taking a crude model of inelastic effects, we shall see that the positions of the resonances are virtually unaffected by such effects, whereas their widths are considerably narrowed. This brings the width closer to the "experimental" value[2] for the P wave. If we then take these resonances, make some simplifying assumptions for the Pomeranchuk Regge trajectory,[3] and impose the Chew-Frautschi saturation condition,[4] we can carry out a fairly simple self-consistent calculation for the high-energy total cross section σ_t. If we repeat the calculation with this value of σ_t in the crossed channel, but this time without imposing the saturation condition in the direct channel, we find that the condition is nevertheless still satisfied to within a few percent. Its original use is thus justified a posteriori.

(a) We shall begin by summarizing some of the results of I and II, whose notation we shall use throughout. Using the N/D method,[5] an effective-range approximation to the distant singularities is set up by making an appropriate approximation for the kernel of the numerator function $N_l^I(\nu)$. Since the nearby part of the left-hand cut can be shown to be unimportant, this gives

$$N_l^I(\nu)=A_{(l)I}(\nu_0)+(\nu-\nu_0)\sum_{i=1}^{n}\frac{F_{(l)I}^{\,i}}{x_i^{-1}+\nu}, \tag{1}$$

where the x_i are given by the kernel approximation. In what follows we shall take, as in II, $x_1=0.16$ and $x_2=0.02$ if $n=2$, and $x_1=0.17$, $x_2=0.07$, and $x_3=0.012$ if $n=3$. The $F_{(l)I}^{\,i}$ and $A_{(l)I}(\nu_0)$ are determined by requiring that the partial-wave amplitude $A_{(l)I}(\nu)\propto\nu^l$ for small ν, and that Eq. (1) gives the same first $(n-l)$ derivatives of $A_{(l)I}(\nu)$ as are given by

$$A_{(l)I}(\nu)=\frac{4}{\pi\nu}\int_0^\infty d\nu'\,\mathrm{Im}\tilde{A}_I\left(\nu',1+2\frac{\nu+1}{\nu'}\right)Q_l\left(1+\frac{\nu'+1}{\nu}\right) \tag{2}$$

at some point ν_F in the nearby left-hand region. As in I, we shall always take $\nu_F=\nu_0=-2$. With $n=2$ for the P wave and $n=3$ for the D wave, a coupled P-D calculation can be carried out, in which it is required that the calculated P- and D-wave resonances have the same positions (ν_R) and widths as the ones contributing to $\mathrm{Im}\tilde{A}_I$ in Eq. (2). Using delta-function approximations, this gives $\nu_R\Gamma_1^{\,1}=4.6$, $\nu_R=5.0$ (mass = 685 MeV) for the P wave and $\nu_R^{\,2}\Gamma_2^{\,0}=4.4$, $\nu_R=9.2$ (mass = 892 MeV) for the D wave. The partial-wave cross sections in the Breit-Wigner approximation have half-widths of about 160 MeV in each case. In the case of the P wave, the corresponding "experimental" mass and half-width, as inferred from pion-production experiments, are 725 to 770 MeV and 30 to 100 MeV, respectively.[2] For the D wave, the mass inferred from the Regge-pole hypothesis is of the order of 1 BeV.[6]

To see how inelastic effects would modify the above results, we shall take a black-disk model above the π - ω threshold ν_I, which is where we may expect such effects to become important.[7] Such a model is known to be a reasonable one for π - N and N - N scattering at intermediate energies, and so we may expect it to apply in this case also.[8] It is equivalent to putting

$$R_l^I(\nu)=1+\theta(\nu-\nu_I)\theta[\nu-(l/r)^2], \tag{3}$$

where $R_l^I(\nu)$ is the ratio of total to elastic partial-