Comments and Addenda

The Comments and Addenda section is for short communications which are not of such urgency as to justify publication in **Physical Review Letters** *and are not appropriate for regular Articles. It includes only the following types of communications: (1) comments on papers previously published in* **The Physical Review** *or* **Physical Review Letters**; *(2) addenda to papers previously published in* **The Physical Review** *or* **Physical Review Letters**, *in which the additional information can be presented without the need for writing a complete article. Manuscripts intended for this section should be accompanied by a brief abstract for information-retrieval purposes. Accepted manuscripts will follow the same publication schedule as articles in this journal, and galleys will be sent to authors.*

Comment on the interpretation of the J particle as a charm-anticharm bound state*

T. Hagiwara and R. N. Mohapatra

Department of Physics, The City College of The City University of New York, New York, New York 10031

(Received 3 April 1975)

Assuming that the 3.1-GeV resonance observed at SLAC and BNL is interpreted as a vector meson belonging to the $\underline{15}+\underline{1}$ representation of SU(4), we remark on its decay width to a lepton pair, using the first spectral-function sum rule for U(4) and the assumption of pole dominance. The observed leptonic decay width, $\Gamma(J\to l\bar{l})$, requires a charge assignment of the quarks, completely different from the conventional one. We propose another way to distinguish between the two assignments.

I. INTRODUCTION

A considerable amount of excitement has been generated by the recent discovery of narrow resonances at 3.105 GeV (J) and 3.695 GeV (J') at BNL and SLAC.[1] At this point there exist various interpretations[2] as to the possible nature of these resonances. In this note, we will consider the viewpoint that the 3.1-GeV resonance is a vector meson belonging to the $\underline{15}+\underline{1}$ representation of SU(4) along with ρ, ω, and ϕ and the 3.7-GeV one is possibly a radial excitation of this state.[2] We will then use the first Weinberg sum rules for U(4) and the assumption of pole dominance to study the decay width to lepton pair $\Gamma(J\to l\bar{l})$ of $J(3.105)$. We find that a knowledge of m_ρ, $\Gamma(\rho\to l\bar{l})$, m_ω, $\Gamma(\omega\to l\bar{l})$, m_ϕ, $\Gamma(\phi\to l\bar{l})$, and m_J is enough to enable one to predict $\Gamma(J\to l\bar{l})$, without making any specific assumption about the quark content of J. We find that $\Gamma(J\to l\bar{l})$ depends on the charge assignment of the quarks. In the case of the *conventional* integral or fractional charge assignment for the quarks, we predict $\Gamma(J\to l\bar{l})\simeq 1.4$ keV. However, experimentally, $\Gamma(J\to l\bar{l})\simeq 5$ keV. We then observe that an unconventional charge assignment[3] of $(\frac{2}{3},-\frac{1}{3},-\frac{1}{3},-\frac{4}{3})$ for the quarks predicts a large $\Gamma(J\to l\bar{l})$, $\simeq 5.5$ keV. We then propose that a study of the two-photon decay mode of the η_c will also distinguish between the two charge assignments of the quarks.

II. FIRST SUM RULE AND $\Gamma(J\to l\bar{l})$

We assume the validity of the first spectral function sum rule for U(4) (defined as usual[3]):

$$\int \frac{\rho^{\alpha\beta}(m^2)}{m^2}\,dm^2 = a\delta_{\alpha\beta}\,. \tag{1}$$

The question of its validity in asymptotically free theories has been discussed in a separate paper[4] and the answer is found to be negative. However, since it is not yet established whether asymptotically free theories describe strong interactions, we will not be discouraged by this. Furthermore, there are models[5] of strong interactions where Eq. (1) can be derived[6]; also, in asymptotically free theories, the corrections to Eq. (1) could be small, in which case, from a phenomenological standpoint, useful information may be derived by ignoring those corrections.

We now proceed to saturate Eq. (1) by the lowest-lying vector-meson states ω, ϕ, ρ, and J. We use the following definitions:

$$\begin{aligned}
(2k_0V)^{1/2}\langle 0|J^0_\mu|v_i\rangle &= \epsilon_\mu(k)\tau_i\,,\\
(2k_0V)^{1/2}\langle 0|J^8_\mu|v_i\rangle &= \epsilon_\mu(k)\sigma_i\,,\\
(2k_0V)^{1/2}\langle 0|J^{15}_\mu|v_i\rangle &= \epsilon_\mu(k)G_i\,,
\end{aligned} \tag{2}$$

where

$v_1=\omega,\quad v_2=\phi\,,\quad v_3=J\,.$

Of course, one easily finds that [see Eq. (1)]

$$a=\left(\frac{G_\rho}{m_\rho}\right)^2 . \tag{3}$$

Now, defining

$$x_i=\left(\frac{\sigma_i m_\rho}{m_i G_\rho}\right),\quad y_i=\left(\frac{G_i m_\rho}{m_i G_\rho}\right),\quad z_i=\left(\frac{\tau_i m_\rho}{m_i G_\rho}\right), \tag{4}$$

one can write down from Eq. (1) that

$$\sum_i x_i^2=\sum_i y_i^2=\sum_i z_i^2=1 \tag{5}$$

and

$$\sum_i x_i y_i=\sum_i y_i z_i=\sum_i x_i z_i=0, \tag{6}$$

where i goes over the ω, ϕ, and J states as defined before. We now write that the electromagnetic current in a general form as follows:

$$J_\mu^{\rm em}=V_\mu^3+\frac{1}{\sqrt{3}}V_\mu^8+\alpha V_\mu^{15}+\beta V_\mu^0 . \tag{7}$$

Note that for $\alpha=-(\frac{2}{3})^{1/2}$ and $\beta=\sqrt{2}/3$ (Case I) we obtain the charge assignment for quarks $(\frac{2}{3},-\frac{1}{3},-\frac{1}{3},\frac{2}{3})$. The integral charges are also obtained for the same values of α and β by adding the "color" contribution to electric charge. On the other hand, if $\alpha=2(\frac{2}{3})^{1/2}$ and $\beta=-2\sqrt{2}/3$ (Case II), we obtain the charge assignment $(\frac{2}{3},-\frac{1}{3},-\frac{1}{3},-\frac{4}{3})$. We can compute the leptonic decay width of ρ, ω, ϕ, and J in terms of x_i, y_i, and z_i. To exhibit this, we define

$$a_i=\left(\frac{m_i\Gamma_i}{m_\rho\Gamma_\rho}\right)^{1/2} \tag{8}$$

and obtain

$$\frac{x_i}{\sqrt{3}}+\alpha y_i+\beta z_i=a_i . \tag{9}$$

Using Eq. (5), Eq. (9) can be rewritten as follows:

$$\sum_i a_i x_i=\frac{1}{\sqrt{3}},\quad \sum_i a_i y_i=\alpha,\quad \sum_i a_i z_i=\beta . \tag{10}$$

Note that we know $a_1\equiv a_\omega$ and $a_2\equiv a_\phi$ and would like to predict $a_3\equiv a_J$. For this purpose we observe the following: x_i, y_i, and z_i are three mutually perpendicular unit vectors and a_i denotes another vector whose dot product with each of them is given. We can therefore rotate x_i, y_i, and z_i to coincide with the coordinate axes; i.e., the rotated $\hat{x}$, $\hat{y}$, and $\hat{z}$ are

$$\hat{x}=(1,0,0),\quad \hat{y}=(0,1,0),\quad \hat{z}=(0,0,1). \tag{11}$$

The vector a will now be rotated and have new $\hat{x},\hat{y},\hat{z}$ coordinates; however, its length is unchanged by rotation. Its length in the rotated frame (which is the same as before rotation, i.e., $\sum a_i^2=\sum \hat{a}_i^2$) is given by Eq. (10) to be

$$\sum a_i^2=(\tfrac{1}{3}+\alpha^2+\beta^2). \tag{12}$$

For $\alpha=-(\frac{2}{3})^{1/2}$ and $\beta=+\sqrt{2}/3$, we find $\sum a_i^2=\frac{11}{9}$. Noting that $a_\omega^2=0.12\pm0.04$ and $a_\phi^2=0.28\pm0.05$ we obtain for this case $\Gamma(J\to l\bar{l})\simeq1.4\pm0.2$ keV, a value lower than that observed experimentally. On the other hand, for $\alpha=2(\frac{2}{3})^{1/2}$ and $\beta=-2\sqrt{2}/3$, we get $\sum a_i^2=\frac{35}{9}$, giving $\Gamma(J\to l\bar{l})\simeq5.5\pm0.2$ keV.

Before we conclude this section, a few remarks are in order on the unconventional quark-charge assignment. First of all, although the concept of a charmed quark became established along with a Weinberg-Salam gauge model based on a SU(2) $\times$U(1) group with doublets of left-handed quarks, we do not assume anywhere in our discussion that we are constructing a model of weak interaction along the lines of gauge theories. Neither do we see how choosing a particular charge assignment for quarks will ever tell anything about the nature of weak currents without further assignment. Secondly, even with the unconventional charge assignment for quarks, one may construct gauge models without any severe problems of $\Delta Q=0$, $\Delta S=1$ neutral currents. For example, if one chooses $SU(4)_L\times SU(4)_R$ as the weak gauge group, there is no reason why the strength of strangeness-changing neutral current couplings will be large at all. It will then depend on whether the gauge bosons W_3^2 mix with gauge bosons of the type W_1^1, W_2^2, W_3^3, etc. One can always avoid such mixings by judicious choice of spontaneous symmetry breaking. In fact we believe that at this point we have no reason to disregard such a possibility, and for this purpose we present the following section and suggest $\eta_c\to2\gamma$ decay as a test of the conclusion we have reached in this section relying on U(4) sum rules.

III. $\eta_c\to2\gamma$ DECAY AND CHARGE ASSIGNMENT OF THE QUARKS

The discussion of the previous section, taken seriously, would suggest a rather unconventional charge assignment for the quarks. However, the above conclusion relies heavily on the assumptions that (a) the contribution of the high-mass resonances [such as ρ', $J'(3695)$, etc.] is negligible and (b) a U(4) spectral sum rule [Eq. (1)] is valid rather than the SU(4) sum rule, i.e.,

$$\int \frac{\rho^{\alpha\beta}(m^2)}{m^2}\, dm^2 = a\delta_{\alpha\beta} + b\delta_{\alpha 0}\delta_{\beta 0}\,. \qquad (13)$$

In this section, we would like to suggest that another way to distinguish between the charge assigments would be provided by a measurement of the two-photon decay width of the SU(4) singlet 0^- meson η' and the SU(3) singlet but SU(4) 15-plet 0^- meson η_c'. To see this, we first assume that the triangle graph dominates their two-photon decays, as is the case for $\pi^0 \to 2\gamma$ decay,[7] and further ignore the mixings among them.[8] Then, assuming U(4) invariance for decay constants, i.e., $f_\eta \approx f_{\eta'} \approx f_{\eta_c'}$, we predict

$$\frac{M(\eta' \to 2\gamma)}{M(\eta \to 2\gamma)} = 5\left(\tfrac{2}{3}\right)^{1/2} \quad \text{(Case I)}$$

$$= 11\left(\tfrac{2}{3}\right)^{1/2} \quad \text{(Case II)}.$$

Similarly,

$$\frac{M(\eta_c' \to 2\gamma)}{M(\eta \to 2\gamma)} = -\sqrt{2} \quad \text{(Case I)}$$

$$= -7\sqrt{2} \quad \text{(Case II)}.$$

These equations will have to be modified if there is significant mixing between η, η', and η_c'. In any case, the two-photon decay mode will provide a clear distinction between the two charge assignments.

IV. CONCLUSION

In summary, we would like to assert that, if $J(3105)$ is a member of the 15+1-dimensional vector multiplet corresponding to SU(4), its leptonic decay width can be studied using first U(4) spectral-function sum rules. The observed leptonic decay width of $J(3105)$ seems to require an unconventional charge structure for the quarks. We then suggest that the two-photon decay model of the η' and η_c' would provide a clear distinction between the different charge assignments mentioned above.

---

*Work supported by the National Science Foundation under Grant No. GP-3809 7X.

[1]J. J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974); J.-E. Augustin *et al.*, *ibid.* 33, 1406 (1974); C. Bacci *et al.*, *ibid.* 33, 1408 (1974).

[2]S. Borchardt, V. S. Mathur, and S. Okubo, Phys. Rev. Lett. 34, 38 (1975); T. Appelquist and H. D. Politzer, *ibid.* 34, 53 (1975); A. De Rújula and S. L. Glashow, *ibid.* 34, 46 (1975).

[3]This point was first noted by V. S. Mathur and T. Goto [University of Rochester report, 1975 (unpublished)].

[4]T. Hagiwara and R. N. Mohapatra, Phys. Rev. D 11, 2223 (1975). See also C. Bernard *et al.*, Phys. Rev. D 12, 792 (1975).

[5]T. D. Lee, S. Weinberg, and B. Zumino, Phys. Rev. Lett. 18, 1029 (1967).

[6]T. Das, V. S. Mathur, and S. Okubo, Phys. Rev. Lett. 18, 761 (1967).

[7]S. L. Adler, Phys. Rev. 177, 2426 (1969).

[8]B. W. Lee, M. Gaillard, and J. Rosner, Rev. Mod. Phys. 47, 277 (1975). If we take the following kind of mixing [as suggested by B. W. Lee and C. Quigg, Fermilab report, 1975 (unpublished)]: $\eta = 0.66 \times \frac{1}{2}(\bar{p}p + \bar{n}n) - 0.75\bar{\lambda}\lambda$, $E \simeq 0.38\,(\bar{p}p + \bar{n}n) + 0.66\lambda\lambda$, and $\eta_c' \simeq \bar{p}'p'$, then our predictions become $M(\eta_c' \to 2\gamma)/M(\eta \to 2\gamma) \approx 4.4$ in case (I) and 17.6 in case (II), leading to estimates of $\Gamma(\eta_c' \to 2\gamma) \approx 600$ keV in case (I) and 10 MeV in case (II). This may lead one to believe that measurement of the photon decay will decide only the mixing scheme of the η's and not the charge assignment. But this is not true, as is clearly seen by noting that the ratio $M(\eta_c' \to 2\gamma)/M(\eta \to 2\gamma)$ is consistently much higher for the case of new charge structure of the quarks regardless of the mixing scheme.