Modified Han-Nambu Model for the e^+e^- Resonances

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(Received 3 February 1975; revised manuscript received 25 March 1975)

Previous considerations of the Han-Nambu model for the new e^+e^- resonances are extended to fit current measurements: exactly two observable narrow resonances; two broad resonances, the $\psi(4.1)$ and another predicted at $\sim 4.9-5.3$ GeV; the $\psi(4.1)$ to comprise two components, of ordinary isospin equal to 0 and 1.

In a previous note[1] (hereafter referred to as I), the predictions of the Han-Nambu model[2] were outlined for the production of neutral mesons in e^+e^- annihilation.[3] It was pointed out that six neutral semicolored[4] mesons were naturally accommodated within that model. Four of these were directly produced through e^+e^- annihilation while the remaining two, denoted by $\psi(\rho^0, 3)$ and $\psi(\rho^0, 8)$, were produced in association with a π^0 meson. It is the purpose of this note to make two additional assumptions, one of which seems to be definitely required by the existing experimental data, which will enable us to make more detailed predictions about the masses and decay characteristics of these six mesons.

In I we assumed what we shall now call the CMP[5] version of the Han-Nambu model. The strong interactions responsible for π^0 emission, etc., relate only to SU(3)$'$. Likewise, the medium-strong interactions are taken to be independent of the group SU(3)$''$: That is, they transform as $H(8,0)$ under the three-triplet group SU(3)$'\otimes$SU(3)$''$. This causes the 72 colored mesons $\psi(i,j)$ (see I), which are degenerate in mass in the absence of the medium-strong interactions, to split into three mass groups, namely $\psi(\varphi,j)$, $\psi(K^*,j)$, and $\psi(\rho,j)$ plus $\psi(\omega,j)$. The notation here is obvious; $j=1-8$ for octet SU(3)$''$, the singlet being $j=0$; and, by analogy with ordinary vector mesons, approximate nonet symmetry in the index i is assumed so that $\psi(\rho,j)$ and $\psi(\omega,j)$ are nearly degenerate in mass. The electromagnetic interactions cause a further mass fine structure within the three main groups.

Thus, the consequence of the CMP version of the Han-Nambu model is mass degeneracy in the index j, under neglect of electromagnetic mass splitting: specifically, between the pairs of neutral mesons $\psi(\rho^0, 3)$ and $\psi(\rho^0, 8)$, $\psi(\omega, 3)$ and $\psi(\omega, 8)$, and $\psi(\varphi, 3)$ and $\psi(\varphi, 8)$. Furthermore, the plausible assumption of approximate nonet symmetry suggests that the four mesons $\psi(\rho^0, 3)$, $\psi(\rho^0, 8)$, $\psi(\omega, 8)$, and $\psi(\omega, 8)$ should differ in mass only by several MeV.

Observation of $\psi(3.1)$ and $\psi(3.7)$ at SPEAR[3] suggests that there is in fact no such mass degeneracy. This leads us to our principal new assumption, namely, that the medium-strong interactions do contain an additional piece transforming as $H(0,8)$ under SU(3)$'\otimes$ SU(3)$''$. We shall call this model the "modified Han-Nambu model" to distinguish it from the CMP version previously discussed. Since the electromagnetic current $j_\mu(0,3)+j_\mu(0,8)+j_\mu(3,0)+j_\mu(8,0)$ exhibits a symmetry under the exchange of its SU(3)$'$ and SU(3)$''$ indices we might expect the medium-strong interactions $H(8,0)+H(0,8)$ to exhibit a similar symmetry. The term $H(0,8)$ would not be immediately apparent in measurements on ordinary hadrons but would have a primary effect on the multiplet structure and decay characteristics of the semicolored mesons. Experiment can readily test this assumption as described below.

As well as removing the mass degeneracy in the SU(3)$''$ index j, $H(0,8)$ will mix the semicolored mesons $\psi(i,8)$ with the originally uncolored mesons $\psi(i,0)$ to produce mesons that we denote by $\psi(i,\varphi)$ and $\psi(i,\omega)$; the $\psi(i,\omega)$ constitute the ordinary mesons in our modified Han-Nambu model. The semicolored mesons $\psi(i,\varphi)$ can obviously decay rapidly to the ordinary mesons $\psi(i,\omega)$ via the interaction $H(0,8)$. Rough estimates of the decay rate[6] suggest a width of order 200 MeV.

Before discussing the mass spectrum of the six semicolored neutral mesons in this modified model, it is worth noting that now the previous $\psi(\rho^0, 8)$ becomes $\psi(\rho^0,\varphi)$ and may be produced directly in e^+e^- annihilation by cooperation of the electromagnetic current $j_\mu(3,0)$ and medium-strong interaction $H(0,8)$. This leaves only $\psi(\rho^0, 3)$ to be produced in association with, say, π^0.

With the addition of $H(0,8)$ each of the three

TABLE I. Mass spectra of 72 colored and semicolored mesons in terms of m^2, ϵ, and δ (see text). The mixing of $\psi(i,0)$ with the colored mesons by means of $H(0,8)$ will produce a small mass shift in $\psi(i,\varphi)$, but this is of second order with respect to the mass splitting induced by $H(8,0)$ and $H(0,8)$ within the colored octet. The table is correct as given to first order.

Particle	Mass
$\psi(\rho,\rho)$; $\psi(\omega,\rho)$	$m^2(1-2\epsilon-2\delta)$
$\psi(K^*,\rho)$	$m^2(1+\epsilon-2\delta)$
$\psi(\varphi,\rho)$	$m^2(1+4\epsilon-2\delta)$
$\psi(\rho,K^*)$; $\psi(\omega,K^*)$	$m^2(1-2\epsilon+\delta)$
$\psi(\rho,\varphi)$; $\psi(\omega,\varphi)$	$m^2(1-2\epsilon+2\delta)$
$\psi(K^*,K^*)$	$m^2(1+\epsilon+\delta)$
$\psi(K^*,\varphi)$	$m^2(1+\epsilon+2\delta)$
$\psi(\varphi,K^*)$	$m^2(1+4\epsilon+\delta)$
$\psi(\varphi,\varphi)$	$m^2(1+4\epsilon+2\delta)$

mass groups discussed in paragraph two splits into a further three subgroups. We list these nine groups in Table I in terms of the unsplit mass-squared parameter m^2 of the colored vector mesons and the parameters ϵ and δ characterizing the respective strengths of the SU(3)′ and SU(3)″ breaking medium-strong interactions $H(8,0)$ and $H(0,8)$. The formulas in Table I extend only to first order in ϵ and δ, since the identifications made below suggest that $\epsilon\approx\delta\approx 0.1$ in all cases.

Lifting of mass degeneracy by $H(0,8)$ means that we expect substantial mass differences between the previously degenerate pairs: $m(\rho^0,3)\neq m(\rho^0,\varphi)$, $m(\omega,3)\neq m(\omega,\varphi)$, and $m(\varphi,3)\neq m(\varphi,\varphi)$. However, we still have the approximate nonet degeneracies $m(\rho^0,3)\approx m(\omega,3)$ and $m(\rho^0,\varphi)\approx m(\omega,\varphi)$. We can now identify the two narrow levels $\psi(3.1)$ and $\psi(3.7)$ with $\psi(\omega,3)$ and $\psi(\varphi,3)$ or vice versa. These levels have $I''=1$ and remain narrow because all states below $\psi(3.1)$ have $I''=0$ and $H(0,8)$ conserves I'' spin as do all the strong interactions. However, we expect that $\psi(3.7)$ can decay to $\psi(3.1)$ with the emission of $(2\pi)_{I=0}$, thus broadening the $\psi(3.7)$ relative to the $\psi(3.1)$. Sample calculations[6] on the associated production of $\psi(\rho^0,3)+\pi^0$ suggest that its cross section is too small to have been observed above the background. This means that the three lowest lying semicolored neutral mesons predicted by this model are consistent with the data reported so far.[3]

If this model is correct, there are still three semicolored neutral mesons yet to be accounted for: namely, $\psi(\rho^0,\varphi)$, $\psi(\omega,\varphi)$, and $\psi(\varphi,\varphi)$. Since, as remarked above, they decay rapidly into ordinary mesons, they would not be observed in a search for relatively sharp resonances because of their small integrated cross section over a narrow energy range. Their existence is not therefore ruled out by the survey of Boyarski *et al.*[7] which failed to find resonances of up to 20 MeV width in the energy range 3.2–5.9 GeV.

Two of the above three mesons, $\psi(\rho^0,\varphi)$ and $\psi(\omega,\varphi)$, will be approximately degenerate in mass and because of the broad width expected (~200 MeV) they should be difficult to separate. The remaining meson is $\psi(\varphi,\varphi)$. We can estimate the mass ratio of these mesons by assuming approximate nonet symmetry in the index i together with constancy of the ratio m_φ/m_ω for all nonets. From the ordinary mesons we see that $m_\varphi/m_\omega=1.30$, which compares with the ratio $3.7/3.1=1.20$ and suggests that $\psi(3.7)$ is $\psi(\varphi,3)$ and $\psi(3.1)$ is $\psi(\omega,3)$. Applying this reasoning to the more massive $\psi(\varphi,\varphi)$ and $\psi(\omega,\varphi)$ we would conclude that

$$1.2\leq m(\varphi,\varphi)/m(\omega,\varphi)\leq 1.3\,. \qquad (1)$$

Now a broad structure in e^+e^- annihilation has been reported[8] at 4.1 GeV. Associating this with $\psi(\omega,\varphi)$ or $\psi(\varphi,\varphi)$, we have, respectively,

$$m(\varphi,\varphi)=4.1\times(1.2\text{–}1.3)=4.9\text{–}5.3\text{ GeV}, \qquad (2a)$$

$$m(\omega,\varphi)=4.1/(1.2\text{–}1.3)=3.2\text{–}3.4\text{ GeV}. \qquad (2b)$$

But (2b) seems precluded by the observations,[8] so our prediction is (2a); there is a hint of such a peak in the measurements,[8] but more definite evidence is needed.

Accordingly, we suggest further exploration of the 4.9–5.3-GeV region along the lines of Ref. 8 to look for a single broad peak. In the 4.1-GeV enhancement it is important to try to separate the contributions of $\psi(\rho^0,\varphi)$ and $\psi(\omega,\varphi)$; for the production of $\psi(\rho^0,\varphi)$ is through $\psi(\rho^0,0)$ and $H(0,8)$ and this is a direct measure of the strength of $H(0,8)$. One possibility of distinction is that the decay products of $\psi(\rho^0,\varphi)$ and $\psi(\omega,\varphi)$ should have ordinary isospin (equivalent to I' spin in our modified Han-Nambu model) equal to 1 and 0, respectively.

We conclude by making the following remarks about the 72 colored mesons: (1) As in I there are 54 colored mesons which can only decay weakly; these mesons may be produced in pairs, or possibly by a neutrino beam [$\psi(i,j)$, where $0\leq i\leq 8$, $j=1,2,4,5,6,7$]. (2) There are nine semicolored mesons which can decay rapidly via $H(0, 8)$ into ordinary hadrons [$\psi(i,\varphi)$, where $0 \leq i \leq 8$]. (3) There are nine semicolored mesons which decay electromagnetically because of conservation of I'' spin [$\psi(i,3)$, where $0 \leq i \leq 8$].

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[4]In I, SU(3)″ octet mesons were called "charmed" or "semicharmed." In order to reserve this designation for SU(4), we replace these terms, respectively, by "colored" and "semicolored" in the present note. We also use the more conventional notation SU(3)′ ⊗ SU(3)″ here instead of SU(3)⊗SU(3)′ as in I.

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UNPHYSICAL SOLUTIONS OF YANG'S GRAVITATIONAL-FIELD EQUATIONS. Richard Pavelle [Phys. Rev. Lett. 34, 1114 (1975)].

On page 1114, first column, eighth line from the bottom, the factor of $\frac{1}{16}$ should read $\frac{1}{6}$.