Possible nature of the ψ particles

A. A. Komar

P. N. Lebedev Physics Institute, USSR Academy of Sciences

(Submitted January 6, 1975)
ZhETF Pis. Red. **21**, No. 5, 309–312 (March 5, 1975)

Assuming that the ψ particles are combinations of p' and $\bar{p}'$ quarks, an explanation is offered for the observed characteristics of these particles. The masses of bosons containing one p' quark are estimated.

PACS numbers: 14.40., 12.40.D, 12.70., 11.30.L

Observation of neutral particles with masses 3105 and 3695 MeV and with unusually small (estimated at about 100 MeV) widths have recently been reported.[1–4] Following,[2] we shall designate these particles by ψ and ψ', respectively. It was also found that ψ' can go over into ψ in accordance with the scheme $\psi' \to \psi + \pi^+ + \pi^-$.

We wish to propose here a possible treatment of the nature of the ψ particles on the assumptions that they are hadrons. We assume henceforth that their spin is equal to unity.

We assume, following Glashow *et al.*,[5] that the usual quark model is supplemented by a p' quark with $T = Y = 0$ and with electric charge $Q_{p'} = Q_p$, the p' quark being the carrier of the new quantum number "charm." From

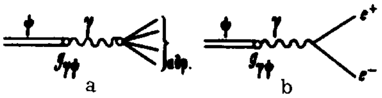

FIG. 1.

the group-theoretical point of view this means the expansion of the $SU(3)$ group to the $SU'(4)$ group.[6-10] We assume that the charm, like strangeness, is destroyed only by weak interactions.

We assume further that the $SU(4)$ group is in fact strongly violated. For example, the p' quark is much heavier than the remaining quarks. In the description of the bosons in group language, this means that the component of the 15-plet with $T=0$ and $Y=0$, namely $V_{15} = (1/\sqrt{12})(\bar p p + \bar n n + \bar\lambda\lambda - 3\bar p' p')$ is strongly mixed with the singlet $V_1 = (1/\sqrt{4})(\bar p p + \bar n n + \bar\lambda\lambda + \bar p' p')$, and in the language of the quark models this means that the state $\bar p' p$ is in practice split away from the states made up of the p, n, and λ quarks.[1)]

Our ground state consists of an ψ particle that is "almost" a pure $\bar p' p$ state with $l=0$ and with spin and parity 1^- (the word "almost" will be explained later on), and the main channel of the decay into $D+\bar D$, where $D^+ = (p'\bar n)$ and $D^0 = (p', \bar p)$ are 0^- particles,[2)] is closed, so that $2m_D > m\psi$. In this case the decay of the ψ particles, owing to the conservation of the charm, can proceed only via a photon (Fig. 1), and it is easily seen that in this case the ratio of the leptonic and hadronic widths would be 1 : 2.5 according to the data on e^+e^- annihilation into hadrons.[11] Since the actual width ratio is 1 : 16, this means that the ψ particle, just as the ϕ meson, contains a small admixture of the state $(1/\sqrt{3})(\bar p p + \bar n n + \bar\lambda\lambda)$ (singlet of the $SU(3)$ group)

$$\psi = \bar p' p' + \epsilon(\bar p p + \bar n n + \bar\lambda\lambda)/\sqrt{3} \tag{1}$$

which uncovers the possibility of direct decays of ψ into pions and kaons.

From the ratio $\Gamma_{e^+e^-}/\Gamma_h = 1:16$ and from the value $\Gamma_{e^+e^-} = 5$ keV we obtain for $\psi(3105)$ $1.2\times10^{-2} \leq \epsilon \leq 1.8\times10^{-2}$, where the limits depend on the degree to which the direct decays into hadrons interfere with the decays via an intermediate photon state (Fig. 1). It was assumed in the calculation that the typical width for the decay of a massive boson into hadrons is ≈200 MeV in the absence of hindrances.

The observed value of the lepton width of $\psi(3105)$, $\Gamma_{e^+e^-} = 5$ keV, can be obtained on the basis of diagram *b* of Fig. 1, under the usual assumption of the vector-dominance model $g_{\gamma\psi} = m_\psi^2 e/f_\psi$, if we use in the calculation $f_\psi^2/4\pi = 10$. We note that the analogous constant for the ϕ meson is $f_\gamma^2/4\pi = 11$.

The structure obtained from formula (1) for ψ indicates also the cause of the small cross section for ψ production in pN (and also πN) collisions.[1] This cross section, according to (1), should be suppressed by at least a factor $\epsilon^2 \approx 10^{-4}$. (A similar but weaker suppression of the cross section takes place for the ϕ meson.)

From the point of view of the discussed model, it is most natural to regard the ψ' particle with mass 3695 MeV as l-excitation of $\psi(3105)$. The observation of $\psi(3695)$ in the e^+e^- annihilation process means that its quantum numbers are 1^-. The simplest assumption is then $l=2$. With this interpretation of ψ', the transition of ψ' into ψ is not forbidden by strong interactions, and the zero isospin of both particles calls for the emission of two pions, as is indeed observed.

In addition to the vector neutral particles, it is natural to expect the model with the p' quark to contain a pseudoscalar particle with structure $\bar p' p'$ plus all possible additions from the remaining quarks. This particle (we shall call it ψ_π) cannot produce a resonance in the e^+e^- annihilation process, and must be sought in other processes, e.g., in $\bar p p$ annihilation, where it can produce a resonance with a characteristic appearance of two γ quanta in the final result.

Starting from the naive quark model we can determine the degree of enhancement of the $\bar p'$ quark and estimate the masses of bosons containing charmed quarks, such as ψ_π, D^0, D^+, and $S^+ = (p'\bar\lambda)$.

It is known that the situation with pseudoscalar and vector particles are best described by formulas with the masses squared. Then the enhancement of the p' quark is given by

$$\delta_{p'} = \frac{1}{2}(m_\psi^2 - m_D^2) \cong 4.5\cdot 10^6\ \mathrm{MeV}^2, \tag{2}$$

whereas $\delta_\lambda = 2.3\times10^5\ \mathrm{MeV}^2$.

We furthermore have for 0^- particles

$$\begin{aligned} m_D &= (\delta_{p'} + m_\pi^2)^{1/2} \cong 2120\ \mathrm{MeV},\\ m_S &= (m_D^2 + \delta_\lambda)^{1/} \cong 2180\ \mathrm{MeV},\\ m_{\psi_\pi} &= (2\delta_{p'} + m_\pi^2)^{1/2} \cong 3010\ \mathrm{MeV}. \end{aligned} \tag{3}$$

We note that actually $2m_D > m_\psi$.

For 1^- particles we have

$$\begin{aligned} m_{D^*} &= (\delta_{p'} + m_\rho^2)^{1/2} \cong 2250\ \mathrm{MeV},\\ m_{S^*} &= (m_{D^*}^2 + \delta_\lambda)^{1/2} = 2300\ \mathrm{MeV}. \end{aligned} \tag{4}$$

The "charmed" hadrons, like their strange analogs, can be produced associatively in strong interactions. It must be emphasized that decay of "charmed" hadrons via weak interactions (with lifetimes $<10^{-12}$ sec) can lead to the appearance of noticeable amounts of muons and electrons of the so-called rapid generation. It is not excluded that the manifestations of such decays have already been observed.[12-14]

The author thanks M.A. Markov for interest in the work. He is also grateful to A.M. Baldin, B.A. Dolgoshein, A.I. Lebedev, and V.A. Petrun'kin for useful discussions.

[1)] Analogously, the state $\bar\lambda\lambda$, which describes in the main the ϕ meson, is split off in the $SU(3)$ group.
[2)] The notation is that of[10].

---

[1] J.J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974).
[2] J.E. Augustin *et al.* Phys. Rev. Lett. **33**, 1406 (1974).
[3] C. Bacci *et al.*, Phys. Rev. Lett. 33, 1408 (1974).
[4] G.S. Abrams *et al.*, Phys. Rev. Lett. 33, 1453 (1974).

[5] S. L. Glashow *et al.*, Phys. Rev. **2D**, 1285 (1970).

[6] P. Tarjanne and V. L. Teplits, Phys. Rev. Lett. **11**, 447 (1963).

[7] Y. Hara, Phys. Rev. **134**, B701 (1964).

[8] W. Krolikowski, Nucl. Phys. **52**, 342 (1964); Nuovo Cim. **33**, 243 (1964).

[9] D. Amati *et al.*, Phys. Lett. **11**, 190 (1964).

[10] J. Bjorken and S. Glashow, Phys. Lett. **11**, 255 (1964).

[11] B. Richter, in: Proc. of the Conf. on Lepton-Induced Reactions, Irvine, California, 1973.

[12] J. P. Boymond *et al.*, Phys. Rev. Lett. **33**, 112 (1974).

[13] J. A. Appel *et al.*, Phys. Rev. Lett. **33**, 772 (1974).

[14] B. A. Dolgoshein *et al.*, Preprint IFVÉ 74-83 (1974).