A possible model of new hadrons

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The properties of new types of elementary particles are discussed in a model in which the quark interaction potential has two minima. Within the framework of this model, the ψ bosons can be constructed out of ordinary quarks.

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Most models used to describe the recently discovered family of elementary particles$^{1)}$ is based on introduction of heavy quarks of a new type (e.g., [2]). In this article an attempt is made to present a more conservative point of view, namely to construct a model of the new bosons by using only the "old" (p, n, λ) quarks. The main premise is that the quark-interaction potential as a function of r has two minima. The new bosons are localized then in the region of the first minimum at $r=0$, and the ordinary hadrons are localized in the region of the second minimum at $r=R_h\approx 1$ GeV^{-1}. We note that potentials of similar type are used to explain certain forms of the isomerism of atomic nuclei; it would therefore be natural to call the new bosons isomer particles.

In the present note we discuss the properties that should be possessed by the potential in order that a noncontradictory picture be obtained, and we formulate the qualitative consequences of such a model.

For the sake of argument we assume that the nonrelativistic model of heavy colored quarks is correct. The main part of the interquark potential is connected with exchange of colored gluons, and the fine structure of potential (its nonmonotonic behavior) is connected with exchange of a nonet of white particles. The potential connected with the colored nonet and the possibility of a nonrelativistic approximation were discussed in[3].

It seems natural that the qualitative results discussed below do not depend on detailed assumptions, particularly on the assumption that the system has a nonrelativistic character. Allowance for the relativistic effects, as well as calculations for concrete forms of the potential, will be dealt with elsewhere.

In the considered model, the levels below the hump of the potential and localized at small r should be narrow, because of the small overlap of their Ψ functions with the Ψ functions of the ordinary hadrons localized at $r\approx R_h$. This is not enough, however. An important role for the new Boson may be played also by the annihilation mechanism of the decay, i.e., in accord with the scheme $q\bar{q}\rightarrow$ gluons $\rightarrow$ hadrons. To suppress the latter it is necessary to assume that the effective mass of the quark (m_{eff}) in the new bosons is larger than m_{eff}, say, in the ρ meson. The latter is possible if the potential depends not only on the distance between the quarks, but also on their energy, which is quite natural in relativistic theories. Now, if an asymptotically free theory holds, then the hadron widths of the isomer particles due to the annihilation mechanism may be located at the required level ~100 keV.[4]

We note that the smallness of the $\psi' \rightarrow \psi\pi\pi$ decay in comparison with $\rho' \rightarrow \rho\pi\pi$ can be explained in part by the PCAC hypothesis[5] and in part by the fact that the ψ bosons are localized at short distances in comparison with the distances that are typical of strong interactions:

$$A(\psi' \rightarrow \psi\pi\pi) \sim \int \Psi^* H \Psi' d^3r \approx H(0) \int \Psi^* \Psi' d^3r = 0 \cdot \qquad (1)$$

Since the width of the well increases sharply above the potential hump, a level should exist near the maximum of the potential, and its width should be large. In the model under consideration there should exist three broad vector levels, two isosinglet and one isovector. The level positions depend on the position of the maximum of the potential for the SU_3-octet state of the quarks with $T=0$ and $T=1$ and for the SU_3-singlet state. It is natural to identify $\psi(4.1)$ and $\psi(4.4)$ with two of these levels. The third level should be expected in the same energy region. The difference between the widths of $\psi(4.1)$ and $\psi(4.4)$ is probably connected with a fortuitous circumstance—the distance between the corresponding level and the maximum of the potential, and hence the degree of spatial localization of the wave function near this maximum. Higher levels, which should also exist, will be much more difficult to observe in *ee* annihilation, since their total width should increase, while the lepton width should decrease (see below).

We consider now leptonic decays of vector mesons. The probability of decay into a lepton pair is equal to

$$\Gamma(V \rightarrow ee) = 16\pi a^2 < Q >^2 |\Psi(0)|^2, \qquad (2)$$

where $\langle Q \rangle$ is the quark charge averaged over the Ψ function. For the components of the octet with $T=1$ we have $\langle Q \rangle^2 = 1/2$, and for the superposition of the octet and the singlet and $T=0$ $\cos\beta|1\rangle + \sin\beta|8\rangle$ we have $\langle Q \rangle^2 = \sin^2\beta/6$.

Experiment yields $\Gamma(\rho \rightarrow ee) = 7$ keV, $\Gamma(\psi(3.1) \rightarrow ee) = 5$ keV, and $\Gamma(\psi(3.7) \rightarrow ee) = 2.5$ keV. Since according to experiment $\psi(3.1)$ and $\psi(3.7)$ are mainly singlets ($\sin\beta \lesssim 1/3$), the agreement between the leptonic widths of ρ and ψ indicates smallness of the ratio $|\Psi_\rho(0) : \Psi_\psi(0)| \lesssim 0.2$, in qualitative agreement with the model. So strong an admixture of the ρ meson at $r=0$ will not lead to large hadronic decays $\psi \rightarrow \rho + \cdots$, since, as noted above, the strong interaction takes place at large distances. As to the admixture of ψ bosons at hadronic distances, it should be small: $|\Psi_\psi(R_h) : \Psi_\rho(R_h)| \lesssim 1/30$. This asymmetry in the distribution of ψ and ρ can be attributed to the already noted dependence of the potential on the energy.

The value $\Gamma(\psi(4.1) \rightarrow ee) = 4$ keV, taking into account the smallness of $\Psi(0)$ for $\psi(4.1)$ in comparison with $\psi(3.1)$, can be reconciled with the model if $\psi(4.1)$ is a component of an octet with $T=1$. As to $\psi(4.4)$, its experimental leptonic width is smaller by a factor 5—10 than that of $\psi(4.1)$, so that $\psi(4.4)$ may be an isotopic singlet.

No isovector states other than $\psi(4.1)$ (?) have been observed in experiment in the 3—4 GeV region. It must therefore be assumed that the octet potential is much narrower than the singlet one, so that either $\psi(4.1)$ is the only level in it or, more interestingly, deeper levels do exist but the spacing between levels is large. A very attractive possibility is that new resonances with masses in the region 2.3—2.4 GeV, of which there has been some talk lately, belong to this family. The widths of these resonances depend on the potential barrier at the given energy and can range from several keV to several MeV. With some optimism, it can be hoped that there exists an entire new family of isomer-particles with different quantum numbers.

We note that one should expect an anomalously large probability of decay of the isomer-particles into lepton pairs, owing to the value of $\Psi(0)$. Therefore, if the total width of the isomer-particles turns out to be small enough, then the relative probability of their weak decays can become appreciable. One cannot exclude the possibility of observing particles of similar type in a neutrino experiment.[6]

Suppression of radiative decays appears to be quite natural in this model. Decays of the type "singlet → singlet + photon" are SU_3-forbidden, and decays of the type "singlet → octet + photon" are suppressed because of the small overlap of the wave functions of the octet and the singlet.

Besides the spatial-isomerism model considered here, there exists another possibility, pointed out to the author by L. B. Okun', wherein the quarks are localized in space in the form of a spherical layer, and the radius of the layer for the ψ bosons is much smaller than the radius of the ordinary hadrons. Spatial configurations of this type were discussed in papers devoted to non-emission of quarks.[7]

Summarizing, we note that the considered model describes qualitatively well the existing situation. From the phenomenological point of view, the difference between the presented scheme and the four-quark model lies principally in the classification of the hadrons. First, there should be no charmed particles. In this sense, a critical question is that of the properties of the states with $m \approx 2.3-2.4$ GeV. In this model, these levels should form an ordinary octet. Further, the existence of the charged partners of $\psi(4.1)$ is predicted, as well as that of a large number of broad levels with different quantum numbers in the region of 4.5 GeV. We note also that consideration of the decay $\chi(3.5) \to \rho + x(2.4)$ causes us to assume that $\chi(4.5)$ is a component of an octet with $J^{PC} = 0^{-+}$.

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[1)] A comprehensive bibliography through June 1975 can be found in the review.[1] Later data were presented at the Stanford conference on Electron and Photon Interactions, August, 1975.

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