LETTERS TO THE EDITOR

THE MINIMAL EXTENSION OF THE CHARM SCHEME AND THE NEW PARTICLES*

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It is shown that the minimal extension of the charm scheme leads almost uniquely to definite predictions for the breaking of the new $(SU_3)_H$ symmetry which appears together with 3 new heavy quarks. This symmetry breaking has different patterns than for the old SU_3. There is no preferred $(SU_2)_H$ subgroup, and the neutral heavy vector mesons are bound states of $\bar{q}q$, practically without mixing. In contrast to the pattern of symmetry breaking, other properties of the new quarks automatically turn out to be the same as in the model of Harari.

The most popular interpretation of the newly discovered particles ψ, ψ', and ψ'' is based on the assumption that there exists a new fourth charmed quark fitting the GIM [2] extension of the Weinberg-Salam model [3]. However, the standard charm scheme leads to the wrong prediction for the ratio $R = \sigma(e^+ + e^- \to \text{hadrons})/\sigma(e^+ + e^- \to \mu^+ + \mu^-)$ ($3\frac{1}{3}$ instead of ~ 5), so it is advisable to study the consequences of a further extension of the charm scheme. It is obvious that one can easily increase the value of R if the existence of additional new heavy quarks is postulated. The new quarks not only increase the R value, but also give a possibility of interpreting the ψ' and ψ'' particles as bound states of these new quarks, and not as the radial excitations of ψ. The phenomenological model, with 6 quarks in which such interpretation of ψ, ψ', and ψ'' is suggested, has been proposed recently by Harari [1].

As it is indicated by the title of this paper our approach to the problem of new particles is based on the gauge theory. More specifically, it means that we assume all features of the charm scheme [4] with colored gauge group SU_3 for strong interactions and $SU_2 \times U_1$

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gauge group for weak and electromagnetic interactions, supplemented by one new postulate, namely the existence of one additional doublet of quarks. The requirement of cancelling the anomalies demands the existence of a new doublet of heavy leptons. So instead of 2 doublets of leptons and two doublets of quarks as in the charm scheme, we assume the existence of 3 doublets of leptons, and three doublets of quarks. This is what we call the minimal extension of the charm scheme. Let us call the quarks forming a new doublet b' and σ' $\begin{pmatrix} b' \\ \sigma' \end{pmatrix}$. They need not be "physical" quarks, but rather objects like λ_c or u_c in the usual theory. As they form the two-dimensional representation of the $SU_2 \times U_1$ group of weak and electromagnetic interactions their charges should be z and $z-1$. It is easy to see that if $z \neq \frac{2}{3}$ one of them should be absolutely stable. In this case there should exist also at least one stable baryon composed of them. Consequently, there should exist a new kind of atoms. Because we do not observe them either on Earth, or in the stars, we have to assume that $z = \frac{2}{3}$ allows the weak decays of such particles into the usual matter. We see that the minimal extension of the charm scheme leads automatically to the charges $(+\frac{2}{3}, +\frac{2}{3}, +\frac{2}{3}, -\frac{1}{3}, -\frac{1}{3}, -\frac{1}{3})$ of the quarks, the same as in [1], and consequently to $R = 5$. Because this value has been reached experimentally, we conclude that all three quark masses are not too distinct. If we are above the threshold for heavy lepton production, the apparent value of R increases to 6. After turning on the mechanism of spontaneous breaking we arrive in the standard way to the "physical quarks" $p, c, b, n, \lambda, \sigma$ which may be grouped in the multiplets

$$\begin{pmatrix} p \\ n_c \end{pmatrix}, \begin{pmatrix} c \\ \lambda_c \end{pmatrix}, \begin{pmatrix} b \\ \sigma_c \end{pmatrix} \tag{1}$$

with

$$\begin{pmatrix} n_c \\ \lambda_c \\ \sigma_c \end{pmatrix} = \hat{C} \begin{pmatrix} n \\ \lambda \\ \sigma \end{pmatrix} \tag{2}$$

where $\hat{C}$ is an orthogonal matrix.

Within the framework of the spontaneously broken gauge theory the orthogonal matrix $\hat{C}$ is completely arbitrary (like the value of the Cabibbo angle in the standard approach), but once it is fixed, the weak interactions of all quarks are completely specified. In particular, it is easy to check that the neutral current is diagonal in all quark fields.

From the phenomenology of weak interactions we know that $c_{11} \approx \cos\theta_c, c_{12} \approx \sin\theta_c$. However, within experimental and theoretical (radiative corrections) uncertainties, the small value ($\lesssim 0.1$) of c_{13} is allowed.

Let us discuss now the strong interaction properties of these new quarks and particles. It is well known [4] that combining the Weinberg-Salam theory of weak interactions with the colored gauge group for strong interactions leads in the charm scheme to the global SU_4 symmetry for strong interactions broken only by the masses of quarks. It is obvious that in this new scheme, in place of SU_4, the SU_6 global symmetry appears. The problem is how it is broken. As we mentioned earlier it seems that all new three quarks have masses which are not very distinct. If in the first approximation we neglect those differences we are immediately led to the approximate $(SU_3)_L \times (SU_3)_H$ symmetry. Both these groups are further broken. We know the breaking pattern of $(SU_3)_L$, so our problem reduces to finding how the symmetry $(SU_3)_H$ is broken. It is practically the same as the question what are the mass differences of c, b and σ quarks. To answer this question we assume that the particles $\psi(3100)$, $\psi'(3700)$ and $\psi''(4100)$ are bound states of the new heavy quark and antiquark pairs similarly as σ, ω and φ are bound states of $\bar{p}p$, $\bar{n}n$ and $\bar{\lambda}\lambda$.

Unfortunately, because the mixing of states occurs, it is not possible to infer the value of quark masses from the masses of observed particles. Some additional information about quark interactions is necessary. We shall try to obtain this information by comparing these two groups of vector mesons and using the SU_6 symmetry of quark interactions. As we shall see, this SU_6 symmetry has to be only roughly satisfied, the final conclusion is not changed even if it is badly violated.

For the sake of comparing the light and heavy vector mesons we have to analyse the σ, ω, φ system on the basis of states $\bar{q}q$, without the explicit use of a special SU_2 subgroup (isospin) which may not exist for the heavy quarks.

In the nonrelativistic quark model, the mass matrix in the first order of perturbation with respect to $m_\lambda - m_p$ would be

$$\begin{pmatrix} a, \varepsilon, \varepsilon \\ \varepsilon, a, \varepsilon \\ \varepsilon, \varepsilon, a+\Delta \end{pmatrix} \tag{3}$$

where a is the sum of twice the quark mass and the expectation values of kinetic and potential energies, $\Delta = 2(m_\lambda - m_p)$ and ε is the transition amplitude $\bar{q}q \to \bar{q}'q'$. One can hope that the above mass matrix has some meaning independently of the nonrelativistic nature of the quark model.

Comparing the eigenvalues of matrix (3) with the experimental masses of ϱ, ω, φ we obtain

$$\varepsilon = (6.5 \pm 5) \text{ MeV}.$$

The parameter ε is very small — nevertheless its presence is crucial for $\bar{p}p$ and $\bar{n}n$ mixing because of the isospin degeneracy. The effect of its smallness is the approximate degeneracy of ϱ and ω mesons, and the small deviation from the "ideal" mixing of φ and ω.

Now let us come back to the ψ, ψ', and ψ'' system. We know that all three masses of vector mesons are in this case *different*. There are only two possibilities. Either two of the 3 heavy quarks are degenerate and ε is very large (of order 200 MeV), or all three quark masses are different. We argue that because of SU_6 symmetry even in the case when it is badly broken the ε for ψ, ψ', ψ'' system has to be small. If the wave functions effects are neglected, the asymptotic freedom tells us that ε, as the measure of the strength of interactions, should decrease when we go from light to heavy quarks. In further discussion we shall not use any particular value of ε. We shall only assume that it is much smaller than the characteristic mass differences between ψ, ψ' and ψ''. This is certainly a reasonable assumption. The rest is almost trivial. Because now the diagonal elements of the mass matrix are all different, we can neglect the small off-diagonal terms. This means that the physical states which we identify with ψ, ψ' and ψ'' are $\bar{c}c$, $\bar{\sigma}\sigma$ and $\bar{b}b$. Such a situation is very simple indeed and one can deduce immediately the consequences. We quote here two of them:

1. There should exist 3 pairs of heavy vector mesons with masses *very close* to $\frac{m_\psi+m_{\psi'}}{2} \approx 3.4$ GeV, $\frac{m_\psi+m_{\psi''}}{2} \approx 3.6$ GeV and $\frac{m_{\psi'}+m_{\psi''}}{2} \approx 3.9$ GeV.

2. The $\Gamma(\psi \to e^+ + e^-) : \Gamma(\psi' \to e^+ + e^-) : \Gamma(\psi'' \to e^+ + e^-)$ should be $4:1:4$.

Many other particles should obviously exist but it is not possible to predict their masses as accurately as for the above heavy vector mesons.

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