ψ particles and new quark models

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It is shown that within the framework of models with five or six quarks it is possible to find a natural explanation for the leptonic widths of $\psi(3095)$ and $\psi'(3695)$ and for the invariance of the K-meson yield in the process $e^+e^-\to$ hadrons in the energy interval from 3 to 4.8 GeV. The value of $R\equiv\sigma(e^+e^-\to$ hadrons$)/\sigma(e^+e^-\to\mu^+\mu^-)$ can be reconciled with the experimental data with and without taking the colors of the quarks into account.

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The description of the recently discovered neutral mesons $\psi(3095)$ and $\psi'(3685)$ within the framework of the quark model with four fundamental quark fields encounters certain difficulties. First, a difficulty arises when it comes to explaining the partial widths of the leptonic decays of these mesons if the fourth quark (the c quark) is assigned the same electric charge $+2/3$ as the p quark, as is done in the Glashow-Iliopoulos-Maiani (GIM) model.[1] In this case, by regarding the ψ as an almost pure bound state $c\bar{c}$ and using the known universality rule[2,3] for the behavior of the wave function of the bound states of two quarks at zero, we obtain

$\Gamma(\psi \to l\bar{l}) \sim 1.5$ keV, as against the experimental value 4.8 ± 0.6 keV.[4] It is also difficult to explain the ratio of the widths,[5] $\Gamma(\psi' \to l\bar{l}) \sim \frac{1}{2}\Gamma(\psi \to l\bar{l})$. Finally, there is no natural explanation for the invariance with respect to the kaon yield in the e^+e^- annihilation into hadrons when the energy is varied from 3 to 4.8 GeV.[6]

We shall discuss possible ways of overcoming these difficulties.

One way out of this situation would be to consider quark models with 5 or 6 quarks. We consider first a 5-quark model, assuming[7] that $\psi \sim ac\bar{c} - bg\bar{g}$ and $\psi' \sim bc\bar{c} + ag\bar{g}$, where g is the fifth quark. Then, with the same universality rule, we find that the leptonic widths of ψ and ψ' can be satisfactorily explained by assigning charges $-4/3$ and $+2/3$ to the c and g quarks. This suggests that it is precisely the fifth quark g which enters in the second weak isodoublet of the GIM model and ensures suppression of the neutral currents with change of strangeness. Taking the weak multiplets in the form $(p,\ n\cos\theta + \lambda\sin\theta)_L$, $(g,\ -n\sin\theta + \lambda\cos\theta)_L$, c_L, $(n,\ c)_R$, p_R, n_R, and g_R we obtain, as can be readily shown, a weak and electromagnetic hadron interaction scheme that preserves the GIM mechanism for suppressing the neutral currents with change of strangeness, but does not contain c-quark into λ-quark transitions in first order in G. Changes of the relative K-meson yield in the process $e^+e^- \to$ hadrons must be expected in this scheme beyond the threshold of production of a pair of mesons with quark content $g\bar{p}$. If one is to trust the $SU(5)$ group mass formulas,[7] this can take place at energy higher than 5 GeV.

From the values of the ψ and ψ' leptonic widths we can obtain different values of the charges of the fourth and fifth quarks, by using the relation indicated in[8] between the leptonic widths of the ρ^0, ω, ϕ, and ψ mesons, in which the leptonic width is determined only by the charges of the component quarks, and does not depend on the meson masses. In this case the values of the leptonic widths of ψ and ψ' are satisfactorily described at c- and g-quark charges $+2/3$ and $-1/3$, respectively. A gauge theory of weak and electromagnetic interactions of hadrons consisting of quarks having these charges was constructed in[9]. In this model, the relative yield of the K mesons in the process $e^+e^- \to$ hadrons, after passing through the threshold of production of meson pairs with quark content $c\bar{p}$ (D mesons) should increase, although not so strongly as in the GIM model, owing to the existence of the $(c,\ n)_R$ doublet. We note that the asymptotic value of $R \equiv \sigma(e^+e^- \to \text{hadrons})\ \sigma(e^+e^- \to \mu^+\mu^-)$ with allowance for three colors of quarks amounts in this scheme to 11/3, as against the experimental value 5 ± 0.5.[6]

We increase the number of quarks to six and consider two models.[1)] Assigning to the new quarks the charges $+2/3$, $-1/3$, and $+2/3$, we can explain satisfactorily the ψ and ψ' leptonic widths by using the new universality rule[8] and regarding ψ and ψ' as $a'\, c\bar{c} - b' g\bar{g}$ and $b'\, c\bar{c} + a'\, g\bar{g}$. On the other hand, by constructing the weak doublets in the form $(p,\ n\cos\theta + \lambda\sin\theta)_L$, $(t,\ -n\sin\theta + \lambda\cos\theta)_L$, $(c,\ g)_L$, $(p,\ g)_R$, $(c,\ n)_R$, and $(t,\ \lambda)_R$, where t is the sixth quark and θ is again the Cabibbo angle, we obtain a model for weak and electromagnetic hadron interactions, in which the relative K-meson yield in the process $e^+e^- \to$ hadrons remains unchanged up to the threshold of production of a meson pair with quark content $t\bar{p}$. The GIM mechanism of suppression of neutral currents with change of strangeness operates here again, and the hadron weak-electromagnetic-interaction gauge theory does not contain any anomalies in the hadron sector. The value of R, with allowance for three colored quarks, is $R = 5$, and its value up to the threshold of the $t\bar{p}$ meson pair production is 11/3.

A scheme with six quarks can also be constructed in a different manner, by choosing the charges of the new quarks to be $-4/3$, $+2/3$, and $-4/3$. This choice of the charges of the c and g quarks corresponds to the use of the old universality rule for the ψ and ψ' leptonic decays, and these mesons are regarded, as before, as bound states of $c\bar{c}$ and $g\bar{g}$ (or of their mixture). Taking the weak multiplets in the form $(p\cos\theta - g\sin\theta,\ n,\ c)_L$ and $(p\sin\theta + g\cos\theta,\ \lambda,\ t)_L$ we can construct a hadron weak electromagnetic interaction gauge model that does not contain neutral currents with change of strangeness. In this model one should not expect a change in the relative kaon yield prior to passage through the threshold for the production of mesons with quark content $t\bar{p}$. The value of R in the scheme with three quark colors, after passing through the threshold for the production of a meson pair with quark content $c\bar{p}$, is $R = 22/3$, while the asymptotic value is $R = 14$.

Thus, within the framework of quark models with five or six quarks, it is quite easy to explain the experimental data that raise difficulties in the $SU(4)$ scheme, without greatly contradicting the values of R measured up to 5 GeV.

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[1)]Models with six quarks were considered also in[10,11].

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