New quarks and baryon spectroscopy

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The masses of new baryons in the multiplets of the $SU(5)$ group are calculated.

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The interpretation of the new particles ψ (3095) and ψ' (3685) as bound states $c\bar{c}$, where c is the fourth quark, presupposes the existence of charmed mesons and baryons. Observation of these mesons and baryons would obviously be the decisive argument in favor of the scheme with four quarks. In[1] the particles ψ and ψ' were considered as bound states $c\bar{c}$ and $g\bar{g}$, where g is a fifth quark. Obviously, this approach again presupposes the existence of mesons and baryons containing the new quarks. The masses of mesons with quark contents $c\bar{p}$, $c\bar{\lambda}$, $g\bar{p}$, $g\bar{\lambda}$, etc. were calculated in[1]. We present here the masses of new baryons with quark contents ppc, ppg, etc.

The experimental searches for charmed mesons and baryons are being carried out quite extensively at present. We shall touch upon certain of the results of these investigations and will discuss briefly their possible interpretation.

In the scheme with five quarks, we describe the baryons, as usual, as bound states of three quarks. The expansion of an arbitrary third-rank spinor into irreducible spinors is written in the form

$$5 \otimes 5 \otimes 5 = 35 \oplus 10 \oplus 40 \oplus 40.$$

The 40-plet of the $SU(5)$ group describes baryons with spin and parity $\frac{1}{2}^+$, and contains the octet of baryons of group $SU(3)$, while the 35-plet of the group $SU(5)$ describes baryons with spin-parity $\frac{3}{2}^+$ and contains the decuplet of the $SU(3)$ group.

Bearing in mind the appreciable mass difference in the fundamental quark multiplet, we must take into account above all the breaking of $SU(5)$ symmetry on account of the mass increases of the quarks: Δ_λ, Δ_c, and Δ_g.

We determine the mass increase of the c and g quarks

Masses of the baryons containing one new quark in the 40-plet ($\frac{1}{2}^+$) and the 35-plet ($\frac{3}{2}^+$) of the $SU(5)$ group.

Quark configuration	$J^P = 1/2^+$	$J^P = 3/2^+$	Charge	
			$Q_c = -4/3$ $Q_g = 2/3$	$Q_c = 2/3$ $Q_g = -1/3$
ppc	2.10	2.40	0	2
$p\lambda c$	2.30	2.54	−1	1
$\lambda\lambda c$	2.47	2.69	−2	0
ppg	2.39	2.69	2	1
$p\lambda g$	2.58	2.84	1	0
$\lambda\lambda g$	2.77	2.98	0	−1

from the masses of the neutral mesons ψ and ψ', assuming the mixing to be ideal[1]:

$$\Delta_c \approx 1/2(m_\psi - m_\omega) \approx 1.156 \text{ GeV},$$

$$\Delta_g \approx 1/2(m_{\psi'} - m_\omega) \approx 1.451 \text{ GeV}.$$

For the increased mass of the strange λ quarks we use the known values $\Delta_\lambda = 0.147$ GeV in the case of the 35-plet and $\Delta_\lambda = 0.188$ GeV in the case of the 40-plet. In addition, account must also be taken of the spin-spin interaction in the quark system, an interaction that leads to the splitting of the masses of the baryons with spin $J = \frac{3}{2}$ and $\frac{1}{2}$, viz., $\Delta m = \alpha J(J+1)$, where $\alpha = (\frac{1}{3})(m_{1236} - m_p) = 0.100$ GeV.

Thus, the masses of the baryons in the 35-plet are described in first-order approximation by the formula

$$M = 0.865 + 0.100J(J+1) + 0.147n_\lambda + 1.16n_c + 1.45n_g, \text{ GeV},$$

where n_λ, n_c, and n_g are the numbers of the λ, c, and g quarks that enter in the composition of the baryon. In the case of the 40-plet, the coefficient of n_λ is equal to 0.188 GeV.

The table lists the masses of the baryons containing one new quark. The last column of the table shows the baryon charges when the charges of the c and g quarks are chosen according to[2].

The decay schemes of the new baryons can be obtained by using the expressions for weak currents in models with five and six quarks, considered in[2]:

$$J_\mu = \bar{p}_L\gamma_\mu n_L \cos\theta + \bar{p}_L\gamma_\mu\lambda_L \sin\theta - \bar{g}_L\gamma_\mu n_L \sin\theta + \bar{g}_L\gamma_\mu\lambda_L\cos\theta + \bar{n}_R\gamma_\mu c_R, \quad Q_c = -4/3,\ Q_g = 2/3;$$

$$J_\mu = \bar{p}_L\gamma_\mu n_L \cos\theta - \bar{c}_L\gamma_\mu n_L \text{son}\theta + \bar{p}_L\gamma_\mu\lambda_L \sin\theta + \bar{c}_L\gamma_\mu\lambda_L\cos\theta + \bar{p}_R\gamma_\mu g_R + \bar{c}_R\gamma_\mu n_R, \quad Q_c = 2/3,\ Q_g = -1/3;$$

$$J_\mu = \bar{p}_L\gamma_\mu n_L \cos\theta - \bar{g}_L\gamma_\mu n_L \sin\theta + \bar{n}_L\gamma_\mu c_L + \bar{p}_L\gamma_\mu\lambda_L\sin\theta + \bar{g}_L\gamma_\mu\lambda_L\cos\theta + \bar{\lambda}_L\gamma_\mu t_L, \quad Q_c = Q_t = -4/3,\ Q_g = 2/3;$$

$$J_\mu = \bar{p}_L\gamma_\mu n_L \cos\theta + \bar{p}_L\gamma_\mu\lambda_L \sin\theta + \bar{t}_L\gamma_\mu\lambda_L\cos\theta - \bar{t}_L\gamma_\mu n_L\sin\theta + \bar{c}_L\gamma_\mu g_L + \bar{p}_R\gamma_\mu g_R + \bar{c}_R\gamma_\mu n_R + \bar{t}_R\gamma_\mu\lambda_R,$$

$$Q_c = Q_t = 2/3,\ Q_g = -1/3.$$

A recent paper[3] reports observation of the event $\nu P \to \mu^-\Lambda^0\pi^+\pi^+\pi^+\pi^-$, which is interpreted as $\nu P \to \mu^- + (ppc)$, $(ppc) \to \Lambda^0\pi^+\pi^+\pi^+\pi^-$ with the mass of the (ppc) state given as $M = 2426 \pm 12$ MeV. From the table and from the expressions for the currents it is seen that this event can be fully interpreted as formation, in the final state, of a baryon with quark content (ppg) in schemes where $Q_g = \frac{2}{3}$ and $Q_c = -\frac{4}{3}$.

We note that in this scheme there exist baryons with charges −3 and −4.

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[1]N. V. Krasnikov and V. A. Kuz'min, ZhETF Pis. Red. **21**, 510 (1975) [JETP Lett. **21**, 235 (1975)].
[2]N. V. Krasnikov, V. A. Kuz'min, K. G. Chetyrkin, *ibid.* **22**, 106 (1975) [**22**, 47 (1975)].
[3]E. G. Cazzoli *et al.*, Phys. Rev. Lett. **34**, 1125 (1975).