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DIQUARK-FOUR QUARK CLUSTER MODEL FOR S = −1 DIBARYONIC RESONANCES

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We present a M.I.T.-like bag model incorporating diquark and chromomagnetic contributions and its predictions concerning S = −1 dibaryons. The model was initialy used to describe non-strange low mass dibaryons.

The investigation has been performed at the Laboratory of High Energies, JINR.

Дикварк-четырехкварковая кластерная модель для дибарионных резонансов с S = −1

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Представлена модель типа MIT-мешка, включающая дикварк и хромомагнитные вклады в применении к дибарионным резонансам с S = −1. Выполнено сравнение с экспериментом.

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1. Introduction

In some previous papers /1/ a model for non-strange low mass dibaryons based on the M.I.T. bag approach has been presented. In the frame of the usual M.I.T. hypothesis /2/, this model, introducing a diquark-four quark cluster structure of the bag in the 3*-3 colour representation and assuming the effect of the chromomagnetic interaction between clusters, leads to a very satisfactory agreement with the bulk of published experimental data /3/. The differences between the experimental values and the predicted ones for the non-strange dibaryonic masses are in general less than 20 MeV/c^2 and may be attributed to the neglection of higher order contribution to the masses

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as spin-spin and spin-orbit interactions. Excepting the model presented in paper [4] (but which does not explain all the experimental data), the low mass non-strange dibaryonic spectra can be completely understood only in this approach. An interesting feature of those calculations is that the agreement is not restricted to the masses of the more frequent (NN) dibaryonic candidates, but also to more complex states, found in ($NN\pi$) invariant mass spectra [5].

In the case of $S=-1$ dibaryons, the conventional M.I.T. bag predictions are in relatively good agreement with the experimental candidates, but an attempt to apply to such states our modified version can be justified by the possibility of understanding both the $S=0$ and the $S=-1$ dibaryons starting from the same basic hypothesis.

In this paper we compute the masses of the strange $S=-1$ dibaryonic resonances and we make some considerations about their stability and decay modes, in terms of a diquark-four quark cluster bag structure.

2. The Mass Values for the S = —1 Dibaryonic Resonances

The lowest mass for the six-quark bag is obtained if we assume that in the s state the bag is made from a diquark and a four-quark cluster in the 3*-3 colour representation of the SU(3) colour group:

$$(q^2)_{3^*} - (q^4)_3 \ . \tag{1}$$

The diquark inclusion is justified by the fact that more conventional two-quark — four-quark state could be stable against the decay into two normal baryons only in the presence of a centrifugal barrier between clusters, namely only in orbitally excited states. As the diquark is considered to be a massive bound state of two (massless) quarks, the diquark wave function would not completely overlap with the wave function of any of the (massless) quarks in the four-quark cluster, even in an s state of the bag, so such configuration would have the possibility of surviving a non-vanishing interval of time before decaing into two baryons.

The M.I.T. mass operator for a six quark bag with such a structure is:

$$M(R) = \frac{4\pi}{3} BR^3 - \frac{z_0}{R} + \sum_{i=1}^{6} N_i \frac{a_i(m_i R)}{R} + m(6;1) \cdot [\Delta_1 + \Delta_2] \, , \tag{2}$$

where: N_i is the quark number operator, B is the bag pressure associated with the properties of Q.C.D. vacuum ($B = 59.2\ \mathrm{MeV{\cdot}fm^{-3}}$), $\alpha_i(m_i R)$ is the energy of the i th quark in the 1s state. In the following we shall consider the non-strange quarks to be massless, and a light strange quark ($m_s = 279$ MeV).

The mass of the state is obtained by minimizing the expectation value of the mass operator (2) with respect to the bag radius. As long as a linear approximation $\alpha_i(r) = \alpha_i(m_i R)$ is valid [6] the radius can be parametrized as [7]:

$$R = r_0 N^{1/3}$$

with $r_0 = 0.72$ fm. In this situation one would get $\alpha(0) = \alpha_n = 403$ MeV fm and $\alpha_s(m_s R) = 570$ MeV fm. m(6;1) denotes the strength of the colour-magnetic interaction in a six-quark bag containing one strange quark (m(6;1) = 54.1 MeV).

The values of the used parameters are those derived in paper [8] from the fit of conventional baryonic and mezonic spectra. Δ_1 and Δ_2 are group-theoretical factors which are dependent on the spin, favour and colour of each component cluster. Their general form is:

$$\Delta = -1/4N(10-N) + 1/3S^2 + 1/2F_c^2 + F_f^2, \qquad (3)$$

where N is the number of quarks in each cluster, S^2 is the squared spin operator, F_f^2 and F_c^2 are squared Casimir operators for the SU(3) colour, respectively for the SU(3) irreducible representations corresponding to each cluster. For the colour representation (1) the eigenvalue of F_c^2 is $f_c^2 = 4/3$.

In order to compute the group theoretical factors Δ_1 and Δ_2 we start from the SU(6) ireps. for the $(q^2)_{3^*}$ and $(q^4)_3$ clusters. These ireps. decompositions into SU(3) colour and SU(2) spin ireps. are presented in Table 1. The decomposition of SU(3) ireps. and the flavour, hypercharge, izospin and spin contents for each possible state are presented in Table 2. The states that contribute to the Y = 1 strange dibaryons are listed in Table 3.

As there are two possibilities of locating the strange quark (in the four-quark cluster or in the diquark), computations have been performed in both hypotheses. Table 3 includes the values for the Δ_1 and Δ_2 group theoretical factors, the quantum numbers as well as the masses for the predicted states.

In order to determine the masses of the orbitally excited states we have assumed that they belong to linear trajectories in the $1 - M^2$ plane:

Table 1. The decompositions of SU(6) ireps. for $(q^2)_{3^*}$ and $(q^4)_3$ clusters in SU(3) and SU(2) ireps.

Cluster	SU(6) irep.	Decomposition
$(q^2)_{3^*}$	{21}	$(3^*,0) \oplus (6,1)$
$(q^4)_3$	$\{210_1\}$	$(3,0) \oplus (3,1) \oplus (6^*,1) \oplus (15,0) \oplus$ $\oplus (15,1) \oplus (15,2) \oplus (15s,1)$
$(q^3)_1$	{56}	$(8,1/2) \oplus (10,3/2)$

$$4\pi\alpha_c = (2\pi\alpha_s B f_c^2)^{-1/2}, \tag{4}$$

where α_c is the colour-dependent Regge slope, $f_c^2 = 4/3$ denotes the eigenvalue of the quadratic Casimir operator of the supposed colour representation, B is the bag pressure and $\alpha_s = g^2/4\pi$, with g being the quark-gluon coupling constant. Finaly, the value of the Regge slope is:

$$1/\alpha_c = (1.1\ \mathrm{GeV}^2)(3/4\ f_c^2)^{1/2} = 1.1\ \mathrm{GeV}^2.$$

The above presented calculations are similar to those performed by Jaffe [9] as including the colour magnetic interaction in the intercept and treating the fine structure as a l-dependent perturbation.

3. Consideration about the Stability and the Decay of the Y 1 Dibaryonic Resonances

The Y=1 dibaryon in the s wave could decay into two colourless baryons which follow the fission of the $(q^4)_3$ cluster. If the colour magnetic interaction determines the stability of the $(q^4)_3$ cluster, the change in the colour magnetic interaction could indicate in what extent the fission of the bag into two colourless parts is energetically favoured [10].

The variation of the strength of the colour magnetic interaction during the fission of the $(q^4)_3$ cluster into one colourless baryon and a quark (that consequently will form the second baryon with the diquark) is measured by:

$$\delta M = M_m(q^4)_3 - M_m(q^3)_1 \simeq m_{12}\Delta_{12}(q^4)_3, \tag{5}$$

and

$$\Delta_{12}(q^4)_3 = \Delta_1(q^4)_3 - \Delta_2(q^3)_1. \tag{5'}$$

Table 2. The flavour, hypercharge, izospin and spin contents f(y, i)s for the states presented in Table 1

Cluster	f(y, i)s content				
$(q^2)_{3^*}$	$3^*(+1/3,1/2)0$	$3^*(2/3,0)0$	6(2/3,1)1	6(−1/3,1/2)1	6(−4/3,0)1	
$(q^4)_3$	3(1/3,1/2)0	3(−2/3,0)0	3(1/3,1/2)1	3(−2/3,0)1		
	$6^*(-2/3,1)1$	$6^*(1/3,1/2)1$	$6^*(4/3,0)1$			
	15(4/3,1)0	15(1/3,1/2)0	15(1/3,3/2)0	15(−2/3,0)0	15(−2/3,1)0	15(−5/3,1/2)0
	15(4/3,1)1	15(1/3,1/2)1	15(1/3,3/2)1	15(−2/3,0)1	15(−2/3,1)1	15(−5/3,1/2)1
	15(4/3,1)2	15(1/3,1/2)2	15(1/3,3/2)2	15(−2/3,0)2	15(−2/3,1)2	15(−5/3,1/2)2
	$15_8(4/3,2)1$	$15_8(1/3,3/2)1$	$15_8(-2/3,1)1$	$15_8(-5/3,1/2)1$	$15_8(-8/3,0)1$	
$(q^3)_1$	8(1,1/2)1/2	8(0,0)1/2	8(0,1)1/2	8(−1,1/2)1/2		
	10(1,3/2)3/2	10(0,1)3/2	10(−1,1/2)3/2	10(−2,0)3/2		

Table 3. The masses of Y = 1 dibaryonic resonances with $(q^2)_{3^*} - (q^4)_3$ structure in different orbital momentum states

a)Strange quark in the $(q^4)_3$ cluster

$(q^4)_3$		$(q^2)_{3^*}$		l = 0	l = 1	l = 2	l = 3
f(y,i)s	Δ_1	f(y,i)s	Δ_2	M (GeV/c^2)			
3(1/3,1/2)1	-10/3	3^*(2/3,0)0	-2	2.006	2.264	2.495	2.707
6^*(1/3,1/2)1	-4/3	3^*(2/3,0)0	-2	2.115	2.360	2.583	2.788
3(1/3,1/2)0	-4	6(2/3,1)1	2/3	2.115	2.360	2.583	2.788
15(1/3,1/2)0	0	3^*(2/3,0)0	-2	2.187	2.425	2.642	2.843
15(1/3,3/2)0	0	3^*(2/3,0)0	-2	2.187	2.425	2.642	2.843
3(1/3,1/2)1	-10/3	6(2/3,1)1	2/3	2.151	2.393	2.613	2.815
15(1/3,1/2)1	2/3	3^*(2/3,0)0	-2	2.223	2.458	2.672	2.871
15(1/3,3/2)1	2/3	3^*(2/3,0)0	-2	2.223	2.458	2.672	2.871
15(1/3,1/2)2	2	3^*(2/3,0)0	-2	2.295	2.523	2.723	2.927
15(1/3,3/2)2	2	3^*(2/3,0)0	-2	2.295	2.523	2.723	2.927
6^*(1/3,1/2)1	-4/3	6(2/3,1)1	2/3	2.259	2.491	2.702	2.899
15(1/3,1/2)0	0	6(2/3,1)1	2/3	2.331	2.556	2.763	2.955
15(1/3,3/2)0	0	6(2/3,1)1	2/3	2.331	2.556	2.763	2.955
15(1/3,1/2)1	2/3	6(2/3,1)1	2/3	2.367	2.589	2.793	2.984
15(1/3,3/2)1	2/3	6(2/3,1)1	2/3	2.367	2.589	2.793	2.984
15_s(1/3,3/2)1	14/3	3^*(2/3,0)0	-2	2.439	2.655	2.855	3.041
15(1/3,1/2)2	2	6(2/3,1)1	2/3	2.439	2.655	2.855	3.041

(continued on the next page)

Table 3 *(continued)*

15(1/3,3/2)2	2	6(2/3,1)1	2/3	2.439	2.655	2.855	3.041
15_B(1/3,3/2)1	14/3	6(2/3,1)1	2/3	2.584	2.788	2.979	3.158
b) Strange quark in the $(q^2)_{3^*}$ diquark							
6^*(4/3,0)1	−4/3	3^*(−1/3,1/2)0	−2	2.115	2.360	2.583	2.788
15(4/3,1)0	0	3^*(−1/3,1/2)0	−2	2.187	2.425	2.642	2.843
15(4/3,1)1	2/3	3^*(1/3,1/2)0	−2	2.223	2.458	2.672	2.871
6^*(4/3,0)1	−4/3	6(−1/3,1/2)1	2/3	2.259	2.491	2.702	2.899
15(4/3,1)2	2	3^*(−1/3,1/2)0	−2	2.295	2.523	2.733	2.972
15(4/3,1)0	0	6(−1/3,1/2)1	2/3	2.331	2.556	2.763	2.955
15(4/3,1)1	2/3	6(−1/3,1/2)1	2/3	2.367	2.589	2.793	2.984
15_B(4/3,2)1	14/3	3^*(−1/3,1/2)0	−2	2.459	2.655	2.855	3.041
15(4/3,1)2	2	6(−1/3,1/2)1	2/3	2.439	2.655	2.855	3.041
15_B(4/3,2)1	14/3	6(−1/3,1/2)1	2/3	2.584	2.788	2.979	3.158

Table 4. The variation of the colour-magnetic interaction. (Eq.5)

a) The strange quark in the $(q^4)_3$ cluster

$(q^3)_1$ / $(q^4)_3$ f(y,i)s	8(0,0)1/2	8(0,1)1/2	10(0,1)3/2	|dM| (MeV/c^2)
3(1/3,1/2)0			*	25.20
3(1/3,1/2)1	*	*		5.60
3(1/3,1/2)1			*	22.40
6^*(1/3,1/2)1	*	*		2.80
6^*(1/3,1/2)1			*	14.00
3(1/3,1/2)0	*	*		8.40
15(1/3,1/2)0	*	*	*	8.40
15(1/3,3/2)0	*	*	*	8.40
15(1/3,1/2)1	*	*		11.20
15(1/3,1/2)1			*	5.60
15(1/3,3/2)1	*	*		11.20
15(1/3,3/2)1			*	5.60
15(1/3,1/2)2	*	*		16.80
15(1/3,1/2)2			*	0.00
15(1/3,3/2)2	*	*		16.80
15(1/3,3/2)2			*	0.00
15_s(1/3,3/2)1	*	*		28.00
15_s(1/3,3/2)1			*	16.80

b) The strange quark in the $(q^2)_3$* diquark

6^*(4/3,0)1	*			2.80
6^*(4/3,0)1		*		14.00
15(4/3,1)0	*	*		8.40
15(4/3,1)1	*			11.20
15(4/3,1)1		*		5.60
15(4/3,1)2	*			16.80
15(4/3,1)2		*		0.00
15_s(4/3,2)1	*			28.00
15_s(4/3,2)1		*		11.20

In order to compute Δ_1 and Δ_2 one has to use also Eq.(3) and the SU(6) irep. {56} for the $(q^3)_1$ singlet. The decompositions in SU(3) and SU(2) ireps. and the $f(j, i)_s$ contents are those presented in Tables 1 and 2 for the $(q^3)_1$ singlet. The dibaryonic stability should increase as the absolute value of δM decreases, so it is reasonable to admit that the widths of the dibaryonic resonances should have the same variation pattern as $|\delta M|$: namely the states with small $|\delta M|$ should have relatively smaller widths.

The variation of the colour-magnetic interaction (Eq.5) was computed in both hypotheses: the strange quark being assumed to belong to the 4-quark cluster or to the diquark. Table 4 lists the obtained values.

For the states with $\ell > 0$, a possible decay mechanism would be by $q-\bar{q}$ pair creation. In order to conserve the angular momentum and the parity, in such transitions $\Delta\ell$ and Δs should be equal to unity.

4. The Comparison with the Experimental Data and with the Conventional M.I.T.-Bag Calculations. Conclusions

In order to compare our predictions with experimental data, we have used the results from nC and π^-C collisions at 7, respectively at 4 GeV/c /11/. These experimental data are in good agreement with those obtained by other groups /12/, and consist mainly in the observation of Λp-dibaryonic candidates. In Table 5 we present our predictions concerning the quantum numbers, the variation of the chromomagnetic interaction (which in the previous paragraph we have claimed to have the same variation pattern as the width of the resonances) and the masses compared to the experimental values of masses and widths, as well as with the conventional M.I.T. predictions for the masses (as quoted in paper /11/). In the same table we have included the $\Lambda p \pi$ candidate /11/ which, in our model, is explained as an orbitally excited dibaryonic state.

One could see that both our predictions (the strange quark assumed to be in the 4-quark cluster or in the diquark) and the conventional M.I.T. ones are in good agreement with the experimental findings, but we should remaind the reader that while the usual M.I.T. calculations are unable to explain the non-strange dibaryonic candidates, our model is applicable to those states, too /1/. The final test able to discerne between our approach and the traditional one would be the unambiguous experimental determination of the quantum numbers of the

Table 5. The comparison with the experimental data /11/ and the results of the conventional M.I.T. bag model

a. $S = -1$ Λp dibaryonic mass results

Experimental results				Conventional M.I.T. calculations		$(q^2)_{3*}-(q^4)_3$ cluster model calculations		
M (MeV/c^2)	Γ (MeV/c^2)	N.S.D.	(μb/^{12}C)	M (MeV/c^2)	J^P	M (MeV/c^2)	|dM| (MeV/c^2)	J^P
2095.0 ± 2.0	7.0 ± 2.0	5.70 ± 1.20	55.0 ± 16.0	2110	1^-	2115	2.8;14;25.2	1^+
2181.0 ± 2.0	3.2 ± 0.5	4.36 ± 1.21	60.0 ± 15.0	2169	1^+	2187	8.4	0^+
2223.6 ± 1.8	22.0 ± 1.9	6.24 ± 1.23	40.0 ± 12.0	2230	0^+	2223	5.6;11.2	$0^+;1^+;2^+$
2263.0 ± 3.0	15.6 ± 2.3	8.55 ± 1.35	85.3 ± 20.0	2241	2^+	2259	2.8;14	$0^+; 1^+;2^+$
2356.6 ± 4.0	98.6 ± 2.5	13.81 ± 1.39	65.0 ± 17.0	2353	1^+	2367	5,6;11.2	$0^+;1^+;2^+$
2129.2 ± 0.3	0.7 ± 0.16	11.37 ± 1.37				2151	5,6;22.4	1^+
ΣN antibound state								

b. $S = -1$ $\Lambda p\pi$ dibaryonic mass results

2495.2 ± 8.7	204.47±5.6	12.86 ± 1.4	90.0 ± 20.0	2500	$0^-;1^-;2^-$	2491	-	$0^-;1^-;2^-$

of the strange dibaryons, as our states are obtained in lower orbital momenta than the M.I.T. ones.

If we agree with the interpretation of the variation of the chromomagnetic interaction during the handronisation of the 4-quark cluster as a quantuty related to the width of the resonance, then the hypothesis of the appartenence of the strange quark to the 4-quark cluster is clearly favoured by the comparison between predictions and experimental data. As in the literature there are enough arguments to consider the role of non-strange diquarks in the hadronic structure /13/, while there is much less evidence for strange ones, we conclude that this variant of our model has more chances to be realistic.

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