BLED WORKSHOPS
IN PHYSICS
VOL. 10, NO. 1
p. 53

Proceedings of the Mini-Workshop
Problems in Multi-Quark States
Bled, Slovenia, June 29 - July 6, 2009

Multi-quark configurations in the baryons

D. O. Riska

Helsinki Institute of Physics, POB 64, 00014 University of Helsinki

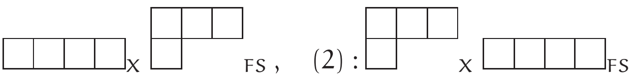
Abstract. Several experiments have revealed the presence of antiquarks in the proton [1]. Extensive phenomenological studies of meson photoproduction on nucleons with unitary hadronic models with and without form factors have also revealed that the well known underproduction of the $N\Delta$ transition strengths by the conventional three quark model may be attributed to the missing "meson cloud" contributions [2]. The question thus arises of to what extent multi-quark configurations of the type $qqqq\bar{q}$, $qqqqq\bar{q}\bar{q}$, ... explicitly contribute to the observable of baryons. Here the contribution of the 5-quark configurations $qqqq\bar{q}$ to the magnetic moments and the axial form factors of the nucleon and the lowest resonances are considered. The two conclusions that emerge are that (a) a combination of at least three different $qqqq\bar{q}$ configurations are required for a satisfactory description of the nucleon properties and (b) that the vanishing of the axial form factor of the $N(1535)$ resonance is a natural consequence of the cancelation of the contributions of the qqq and $qqqq\bar{q}$ configurations [3].

1 The $qqqq\bar{q}$ configurations in the nucleon

The $qqqq$ subsystem of a $qqqq\bar{q}$ configuration has to be completely antisymmetric. As there are only 3 colors, the most "antisymmetric" qqqq color configuration is the mixed symmetry configuration $[211]_C$.

$[211]_C$: $_C$, $[31]_{XFS}$: . (1)

The complete antisymmetry of the $qqqq$ system therefore requires that the combined space-flavor-spin configuration has to have the (conjugate) mixed symmetry combination $[31]_{XFS}$ above. This can be achieved by either (1) choosing the spatial configuration to be completely symmetric $[4]_S$, with the flavor-spin configuration $[31]_{FS}$ or (2) by choosing the latter to be completely symmetric $[4]_{FS}$ and the former to have the mixed symmetry $[31]_X$:



(1) : $_X$ $_{FS}$, (2) : $_X$ $_{FS}$. (2)

In the first case positive parity demands that the antiquark $\bar{q}$ be in the $P-$state, while in the latter case, the antiquark has to be in the ground ($S-$) state. A pion

Table 1. Magnetic moments for the $qqqq\bar{q}$ configurations in the nucleon

$qqqq$ symmetry configuration	proton	neutron	
$[31]_X[4]_{FS}[22]_F[22]_S$	0	1/3	
$[31]_X[4]_{FS}[31]_F[31]_S$	2/9	-2/9	$qqqq : J = 1$
$[31]_X[4]_{FS}[31]_F[31]_S$	-1/3	0	$qqqq : J = 0$
$[4]_X[31]_{FS}[22]_F[31]_S$	7/27	-23/27	$\bar{q} : J = 3/2$
$[4]_X[31]_{FS}[22]_F[31]_S$	-4/27	0	$\bar{q} : J = 1/2$
$[4]_X[31]_{FS}[31]_F[22]_S$	-2/9	0	
$[4]_X[31]_{FS}[31]_F[31]_S$	-19/27	1/9	$\bar{q} : J = 3/2$
$[4]_X[31]_{FS}[31]_F[31]_S$	508/729	-95/729	$\bar{q} : J = 1/2$

loop configuration would correspond to the antiquark in the P$-$state. The configuration with the $\bar{q}$ in the S$-$state is, however, that which is consistent with a positive strangeness magnetic moment [4,5]. Note that if the antiquark is in the P$-$state the required $[31]_{XFS}$ configuration can also be obtained with $[31]_{FS}$ and $[22]_{FS}$ flavor-spin configurations of higher energy [20].

No $qqqq\bar{q}$ component alone can achieve the remarkable $-3/2$ ratio between the proton and the neutron magnetic moments, which is characteristic of the basic qqq configuration in both its nonrelativistic and relativistic versions [6]. This may be inferred from Table 1, where the nucleon magnetic moments for the 7 possible $qqqq\bar{q}$ configurations in the nucleons are listed. This may also inferred from the comprehensive attempt in ref.[7] to combine only the first of these $qqqq\bar{q}$ configurations with the basic qqq configuration.

The desired -3/2 ratio can however be obtained with a linear combination of the qqq and the first 3 configurations in the table:

$$\psi = \sqrt{P_3}\varphi_{[3][21][21]} + \sqrt{\frac{P_5}{\frac{11}{9}b_1 + \frac{5}{3}b_2}}\left\{\sqrt{\frac{2}{9}b_1 + \frac{2}{3}b_2}\varphi_{[4][22][22]} + \sqrt{b_1}\varphi^{J=1}_{[4][31][31]} + \sqrt{b_2}\varphi^{J=0}_{[4][31][31]}\right\}. \tag{3}$$

Here P_3 and P_5 are the probabilities for the qqq and (total) $qqqq\bar{q}$ components. The symmetry assignments [FS][F][S] in the wave functions represent flavor$\times$spin, flavor and spin respectively. The $\bar{q}$ components in the $qqqq\bar{q}$ wavefunctions is to be understood. A combination of the form (3) with 68 % qqq and 32 % of these $qqqq\bar{q}$ can in fact be arranged to yield the empirical value for $g_A(n \to p)$, eg by taking $b_1 = b_2$.

The identification of specific multi-quark contributions in the nucleon form factors is difficult because of their smooth behavior, which may be reproduced by a large variety of models. The prospective node in the region above $Q^2 \sim 6$

GeV^2 in G_E^p [8] does for example arise naturally already in the case of the qqq configuration if calculated with front form kinematics [9], although it also arises if a $qqqq\bar{q}$ component is included, the magnitude and form of which are set by the empirical values for G_E^n [10]. The electric form factor of the neutron G_E^n, which vanishes in the nonrelativistic qqq model, can in fact be brought into agreement with the empirical values by including a mixed symmetry $S-$state in the nucleon wave function with a probability of $1 - 2$ % [9].

2 The $qqqq\bar{q}$ configurations in the nucleon resonances

While it is possible to achieve a qualitative description of the lowest baryon resonances with the basic qqq model with spin and flavor dependent interactions [11], that model does not describe the systematics of the resonance decay widths. In the case of the $\Delta(1232)$ and the $N(1440)$ resonances it has been shown that the inclusion of a $qqqq\bar{q}$ component in the wave function makes it possible to overcome the underpredictions of the electromagnetic and strong decay widths [12–14]. Such calculations are however only qualitative in that the cross term matrix elements between the qqq and $qqqq\bar{q}$ components are very sensitive to the wave function models.

The cross terms between the qqq and the $qqqq\bar{q}$ configurations are large when the operator, which connects the annihilating $q\bar{q}$ pair and the meson or the γ ray involves the "large" components of the Dirac spinors. When the operator involves the small components, which is the case of the axial charge operator, the cross terms are suppressed.

In this context the recent lattice result that the axial charge of the $N(1535)$ is very small - if not 0 - is particularly interesting [15]. If the corresponding result for the (near) parity partner $N(1440)$ would also be close to 0, that might actually indicate the onset of restored chiral symmetry [16]. As the configuration mixing between the $N(1535)$ and the following $1/2^-$ resonance $N(1650)$ is expected to be small [17,18], these resonances may be considered separately.

The general expression for the axial charge of the $N(1535)$ is

$$g_A^* \simeq \sum_n A_n P_n\,, \quad n = 3, 5, .. \tag{4}$$

where n is the number of constituents ($(n+3)/2$ is the number of quarks and $(n-3)/2$ the number of antiquarks). Since the qqq model value for g_A^* is $-1/9$ [16], it follows that if indeed the axial charge of the $N(1535)$ vanishes, the multiquark configurations with $n > 3$ have to cancel that value.

Consideration of the $qqqq\bar{q}$ components indicates that this would be a very natural result [3]. In Table 2 all the possible $qqqq\bar{q}$ configurations in the $N(1535)$ and the corresponding coefficients A_n in the axial charge expression 4 are listed. These are listed in order of increasing energy under the assumption that the interaction between the quarks depend on spin and flavor or color.

Inclusion of these $qqqq\bar{q}$ components in addition to the qqq component leads to the axial charge expression,

$$g_A(N(1535)) = -\frac{1}{9}P_3 + \frac{5}{6}P_5^{(2)} - \frac{1}{9}P_5^{(3)} - \frac{4}{15}P_5^{(4)} + \frac{17}{18}P_5^{(5)}\,, \tag{5}$$

Table 2. The $qqqq\bar{q}$ configurations in the $N(1535)$ and the corresponding axial charge coefficient A_n (4) [19].

configuration	$qqqq$ flavor-spin	$qqqq$ color-spin	A_n
1	$[31]_{FS}[211]_F[22]_S$	$[31]_{CS}[211]_C[22]_S$	0
2	$[31]_{FS}[211]_F[31]_S$	$[31]_{CS}[211]_C[31]_S$	$+5/6$
3	$[31]_{FS}[22]_F[31]_S$	$[22]_{CS}[211]_C[31]_S$	$-1/9$
4	$[31]_{FS}[31]_F[22]_S$	$[211]_{CS}[211]_C[22]_S$	$-4/15$
5	$[31]_{FS}[31]_F[31]_S$	$[211]_{CS}[211]_C[31]_S$	$+17/18$

where the coefficients P indicate the corresponding probabilities. Because two of the $qqqq\bar{q}$ components have large positive coefficients, while the qqq contribution has a small negative coefficient it is possible to cancel the latter contribution altogether with only modest probabilities of the $qqqq\bar{q}$ components [19].

Combination of this result with the lattice calculation result for the axial charge of the $N(1650)$ resonance [15], which is close to the qqq quark model value $5/9$ [16], suggests the conclusion that the smallness of the axial charge of the $N(1535)$ is a natural consequence of its quark configuration and (possibly also) the cancelation between the contributions of the qqq and the $qqqq\bar{q}$ components [19] rather than an indication of restored chiral symmetry.

References

1. G.Garvey and J.C.Peng, Prog.Part.Nucl.Phys. **47**, 203 (2001)
2. B. Juliá-Díaz et al., Phys. Rev. **C 75**, 015205 (2007)
3. C. S. An and D. O. Riska, Eur.Phys.J **A37**, 263 (2008)
4. B. S. Zou and D. O. Riska, Phys. Rev. Lett. **95**, 072001 (2005)
5. J. Liu, R. D. McKeown and M. Ramsey-Musolf, Phys. Rev.**C 76**, 025202 (2007)
6. B. Juliá-Díaz and D. O. Riska, Nucl. Phys. **A 739**, 69 (2004)
7. C. S. An, Q. B. Li and D. O. Riska, Phys. Rev. **C 74**, 055207 (2006), **C 75**, 069901 (2007)
8. O. Gayou et al.. Phys. Rev. Lett. **88**, 092301 (2002)
9. B. Juliá-Díaz, D.O. Riska and F. Coester, Phys. Rev. **C 69**, 035212 (2004), **C75**, 069902 (2007)
10. Q. B. Li and D. O. Riska, Nucl.Phys. **A 791**, 406-421 (2007)
11. L. Ya. Glozman and D. O. Riska, Phys. Rept. **268**, 263 (1996)
12. Q. B. Li and D. O. Riska, Phys.Rev. **C 73**, 035201 (2006)
13. Q. B. Li and D. O. Riska, Nucl.Phys. **A 766**, 172 (2006)
14. Q. B. Li and D. O. Riska, Phys.Rev. **C 74**, 015202 (2006)
15. T. T. Takahashi and T. T. Kunihiro, Phys. Rev. **D 78**, 01150(R) (2008)
16. L. Ya. Glozman and A. V. Nefediev, Nucl. Phys. **A 807**, 38 (2008)
17. J. C. Nacher et al., Nucl. Phys. **A 678**, 187 (2000)
18. D. Pirjol and C. Schat, arXiv: 0906.0802 [hep-ph]
19. C. S. An and D. O. Riska, Eur.Phys.J. **A37**, 263-265 (2008)
20. C. Helminen and D. O. Riska, Nucl. Phys. **A699**, 624 (2002)