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QCD SUM RULES FOR THE 70-PLET BARYONS

T. Aliev and V. Zamiralov *

Institute of physics, Baku, Azerbaijan and Physical Department,

Middle East Technical University, Ankara, Turkey, taliev@metu. edu.tr,

** Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Moscow, Russia, zamir@depni .*

ABSTRACT

Magnetic moments of the positive parity 70-plet baryons are estimated within the nonrelativistic quark model and QCD sum rules method. It is found that the magnetic moments of the 70-plet baryons can be expressed in terms of the D and F couplings. Results reproduce the nonrelativistic quark model predictions and exhibit unitary symmetry pattern.

Keywords: *nonrelativistic quark model, QCD sum rules*

Study of the electromagnetic properties of hadrons represents very important source of information about their internal structure and can provide valuable insight in understanding the mechanism of strong interactions at low energies, i.e., about nonperturbative aspects of QCD. Particular interest deserves magnetic moments of baryons as the subject of permanent study due to growing experimental information [1]. Magnetic moments of the positive parity octet and decuplet baryons are studied in framework of different approaches such as nonrelativistic quark model (NRQM) [2], static quark model [3], QCD string approach [4], chiral perturbation theory [4], Skyrme model [5], traditional QCD sum rules [6], light-cone version of QCD sum rules [7], lattice QCD [8].

Shortly we discuss construction of QCD sum rules introduced in [9], [10].

The starting point is polarization operator (correlator) for Σ -like hyperons. Excplicitly we write it for Σ^0 - hyperon:

$$\Pi^{\Sigma} = i \int dk\, d^4 x \exp(ipx) \langle 0|T\{\eta^{\Sigma}(x), \eta^{\Sigma}(0)\}|\gamma\rangle, \qquad (1)$$

where interpolating currents (in some way analogue of the baryon wave functions in NRQM) could be chosen as

$$\eta^{\Sigma 0}(x) = [u^{aT} C s^b \gamma_5 d^c - d^{aT} C s^b \gamma_5 u^c - (C s^b \gamma_5 \to C \gamma_5 s^b x)], \qquad (2)$$

where a, b, c are the color indices, C is the charge conjugation matrix. Other baryon currents (but that of Λ) are written by changing quark symbols.

The idea of the **QCD sum** rules [9],[10] could be stated as follows: polarization operator is calculated in two different schemes:

(1) Upon using some phenomenological pole model saturated by baryon poles and resonances plus high energy contributions;

(2) Upon performing Wilson operator product expansion (OPE) and calculating quark diagrams with insertions of non-zero vacuum expectation values.

Putting them equal and performing Borel transformation one arrives at desired sum rule .

We can write QCD sum rules for the magnetic moments of Σ -like octet 56-plet baryons μ_B [7, 11] as

$$a_B^2 \mu_B \exp(-m^2/M^2) = (e_u + e_d)\, \Pi_1(u, d, s) + e_s \Pi_2(u, d, s), \qquad (3)$$

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while for the Λ-hyperon we obtain result with the use of the relations from [11]. The $a_{B\ are}$ so-called Borel residue, M is characteristic parameter of the Borel transformation and Π_i can be found in [6] and [12].We have shown earlier that unitary symmetry plays essential role in the QCD sum rules in relating various couplings through well-known F- and D-type structures reducing number of independent correlation functions to minimum. We would show here in what way unitary pattern of the QCD sum rules arrives. We remind in what way SU(3) description in tems of F- and D couplings arrives in NRQM. Let us begin with the discussion of the 56-plet baryon octet $1/2^+$ in SU(3) and assume that photon interacts in a different way with two quarks of similar flavor of the Σ-like baryon B(qq, Q) and with a single quark Q. As an example let the magnetic moment operator has the form $e_q w_q a^q$, where new operator w_q just differs between a single Q quark and a biquark ($q_\uparrow q_\uparrow$) or ($q_\uparrow q_\downarrow$) through the matrix elements

$$< q_\uparrow q_\uparrow,Q_\downarrow|w_q| q_\uparrow q_\uparrow,Q_\downarrow>=w_{\uparrow\uparrow},\ \ < q_\uparrow q_\downarrow,Q_\uparrow|w_q| q_\uparrow q_\downarrow,Q_\uparrow>=w_{\uparrow\downarrow},$$
$$<q_\uparrow q_\uparrow q_\uparrow,Q_\downarrow|w_Q| q_\uparrow q_\uparrow,Q_\downarrow>=v_{\uparrow\uparrow},\ \ < q_\uparrow q_\downarrow,Q_\uparrow|w_Q| q_\uparrow q_\downarrow,Q_\uparrow>=v_{\uparrow\downarrow}. \tag{4}$$

Then magnetic moment of the proton p(uu,d) yields:

$$\mu_p=\sum<p\uparrow|e_q\, w_q\, \sigma_z^q\ |p\uparrow>=1/\sqrt{18}\ <2u_1 u_1 d_2-u_1 d_1 u_2 -d_1 u_1 u_2 +2u_1 d_2 u_1-u_1 u_2 d_1 -d_1 u_2u_1$$
$$+2d_2 u_1 u_1-u_2 u_2 d_1 - u_2d_1 u_1 \mid e_q\, w_q\, \sigma_z^q \mid p\uparrow>$$
$$=(4/3) \mid e_u\, w_{\uparrow\uparrow} - e_d\,(2\, v_{\uparrow\uparrow} -v_{\uparrow\downarrow}) = e_u\, 2\mu_F+e_d(\mu_F-\mu_D) \tag{5}$$

with $w_{\uparrow\uparrow} = 3\mu_F /2$, $w_{\uparrow\downarrow}=\mu_D$, $(2\, v_{\uparrow\uparrow} -v_{\uparrow\downarrow})/3=(\mu_F-\mu_D)$. (It is worth noting that the assumption $w_{\uparrow\uparrow} = w_{\uparrow\downarrow}$ yields F/D = 2/3 !)

The main results are:

• The F coupling is related to the interaction of the γ with 'biquark' composed of two quarks of (almost) equal flavour and the same spin projections

• The (F - D) is related to the interaction of the γ with the single quark

Magnetic moment of the photon to Σ°(ud,s) containing two quarks *u, d* in a biquark state and a single quark *s* would have the form similar to that of the QCD sum rules of (3)

$$\mu_B = (e_u + e_d)F + e_s\,(F\text{-}D) \tag{6}$$

Now we try to transfer this reasoning to the QCD sum rules of baryons with spin ½ of the 70-plet.

Let us analyze magnetic moments of baryons entering 70-plet representation SU(6) with decomposition 70 = (8,2) + (10,2) + (8,4) +(1,2) in framework of NRQM and quark-diquark model. The wave functions of 70-plet within the NRQM were obtained in a number of works (see [13] and references therein). Following [13] the wave function of N^{*+} state in 70-plet with positive parity can be written as

$$\sqrt{18}\ |N^{*+}>=|2u_1 u_1 d_2-u_1 d_1 u_2 -d_1 u_1 u_2 -u_1 d_2 u_1-u_1 u_2 d_1$$
$$+2d_1 u_2 u_1 -d_2 u_1 u_1-u_2 u_1 d_1 +2\, u_2d_1 u_1 > \tag{7}$$

Using this wave function with the modified operator for the magnetic moment form $e_q w_q a^q$ for N* we get

$$\mu_{N^{*+}}= e_u\, 2/3(2w_{\uparrow\uparrow} +w_{\uparrow\downarrow})+ e_d\ 1/3\,(2\, v_{\uparrow\uparrow} +v_{\uparrow\downarrow}) = e_u\, \mu_F+e_d(2\mu_F-\mu_D) \tag{8}$$

with $w_{\uparrow\uparrow} = 3\mu_F /2$, $(2\, v_{\uparrow\uparrow} -v_{\uparrow\downarrow})/3=(\mu_F-\mu_D)$.

In a way similar for 56-plet one can predict the magnetic moments of the octet in 70-plet. in terms of D- and F- quantities and their NQRM limit with D=1, F=2/3 and e_q changed to μ_q

$$\mu_{N^{*+}}= e_u\, \mu_F+e_d(2\mu_F-\mu_D) \rightarrow 2/3\ \mu_u +1/3\ \mu_d,$$

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$$\mu_{\Sigma^{*+}} = e_u \mu_F + e_s(2\mu_F - \mu_D) \rightarrow 2/3\ \mu_u + 1/3\ \mu_s,$$
$$\mu_{\Sigma^{*0}} = ½(e_u + e_d)\ \mu_F + e_s(2\mu_F - \mu_D) \rightarrow 1/3\ \mu_u + 1/3\ \mu_d + 1/3\ \mu_s, \quad (9)$$
$$\mu_{\Lambda^*} = 1/6(e_u + e_d)(9\ \mu_F - 4\ \mu_D) + 1/3 e_s \mu_D \rightarrow 1/3\ \mu_u + 1/3\ \mu_d + 1/3\ \mu_s,$$

in accord with the NRQM results [13].

Let us now assume that the same transformations from μ_p to $\mu_{N^{*+}}$ in NRQM and quark-diquark model hold in QCD sum rules framework, i.e. at interpolating current level. In this case even when the explicit expressions for interpolating currents of octet baryons belonging to the 70-plet representation are not known, one can predict the magnetic moments of these baryons. Derivation of sum rules for 70-plet baryons follows this reasoning. QCD sum rules for Σ-like octet 70-plet can be written in the form similar to eq. (3);

$$\Pi^{\Sigma 0^*}(u, d, s) = 1/2(e_u + e_d + 2e_s)\ \Pi_1\{u, d, s) + e_s\ \Pi_2(u, d, s), \quad (10)$$

while for the Λ^*-hyperon we obtain result with the use of the relations from [11]. Comparing these relations with sum rules for the $\Sigma°$ and Λ baryons of the 56-plet we see that they change itself drastically and this constitutes the main result of this work.

As examples we cite only few of them, the rest can be found in [14]: $\mu_{N^{*+}}$ changes from =2.72 μ_N to 0.83 μ_N, $\mu_{\Sigma^{*+}}$ changes from 2.52 μ_N to 0.70 μ_N, μ_{Λ^*} changes from -0.50 μ_N to -0.11 μ_N.

Thus it is shown that octet baryons in the 70-plet can be analyzed in the way similar to those of 56-plet. In particular magnetic moments are written in terms of the D and F quantities characteristic for octet coupling. Moreover the main formulas for the magnetic moments are written in such a way as to obtain the NRQM results as well as unitary symmetry ones. Borel QCD sum rules are constructed for the magnetic moments of the 70-plet octet.

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