ԵՐԵՎԱՆԻ ՖԻԶԻԿԱՅԻ ԻՆՍՏԻՏՈՒՏ
ЕРЕВАНСКИЙ ФИЗИЧЕСКИЙ ИНСТИТУТ

ЕФИ-551(38)-82

I.G.AZNAURYAN, A.S.BAGDASARYAN,
N.L.TER-ISAAKYAN

MAGNETIC MOMENTS OF BARYON OCTET IN RELATIVISTIC QUARK MODEL

ԵՐԵՎԱՆ 1982 ЕРЕВАН

ЕФИ-55I(38)-82

I.G.AZNAURYAN, A.S.BAGDASARYAN,
N.L.TER-ISAAKYAN

MAGNETIC MOMENTS OF BARYON OCTET IN RELATIVISTIC QUARK MODEL

Magnetic moments of baryon octet are considered in a relativistic quark model under the simple assumption that the SU(3)-breaking effect arises due to strange and nonstrange quark mass difference. An excellent description of all baryon magnetic moments is obtained. The $\Sigma^0 \to \Lambda\gamma$ transition magnetic moment turned out 2σ lower than its experimental value.

Yerevan Physics Institute
Yerevan 1982

ЕФИ-55I(38)-82

И.Г.АЗНАУРЯН , А.С.БАГДАСАРЯН,
Н.Л.ТЕР-ИСААКЯН

МАГНИТНЫЕ МОМЕНТЫ ОКТЕТА БАРИОНОВ В РЕЛЯТИВИСТСКОЙ КВАРКОВОЙ МОДЕЛИ

Магнитные моменты октета барионов рассматриваются в релятивистской кварковой модели в предположении простейшего механизма нарушения $SU(3)$ - симметрии за счет утяжеления массы странного кварка. Получено хорошее описание всех магнитных моментов, кроме магнитного момента перехода $\Sigma^0 \to \Lambda\gamma$,который оказался на два стандартных отклонения ниже экспериментального значения.

Ереванский физический институт
Ереван I982

ЕФИ-55I(38)-82

YEREVAN PHYSICS INSTITUTE

I.G.AZNAURYAN, A.S.BAGDASARYAN,
N.L.TER-ISAAKYAN

MAGNETIC MOMENTS OF BARYON OCTET IN RELATIVISTIC QUARK MODEL

Yerevan 1982

Recently for the first time the magnetic moment of the Ξ° hyperon has been measured with a very high precision[1], the data on μ_{Ξ^-}[2], μ_Λ[1], μ_{Σ^-}[3] and μ_{Σ^+}[3] have been essentially improved. As a result, all baryon magnetic moments are known to a reasonable degree of accuracy, which permits one to test different approaches of quark models. Many authors (see e.g. [4-6] and references therein) have considered baryon magnetic moments but none of the theoretical approaches used so far has given an overall satisfactory fit. Difficulties arise in the description of the Σ and Ξ hyperon magnetic moments. As it is shown in Ref.[7] , the disagreement between theory and experiment cannot be eliminated in the framework of quark models by symmetry breaking, configuration mixing or quark-diquark correlations. Some mechanism for quenching the contributions of the magnetic moments of the nonstrange quarks in hyperons relative to their contributions in the nucleon must be introduced to fit present data in such models.

In this work we consider the magnetic moments of the strange baryons in the relativistic quark model[8-13] which are applied successfully in[12, 13] to the description of the nucleon magnetic moments, electromagnetic radii and G_A/G_V ratio for nucleon. From our analysis [12, 13] it followed unambiguously that constituent quarks in nucleon must be relativistic and that the success of the nonrelativistic quark model when describing ratios μ_p/μ_n,

G_A/G_V and relations between nucleon radii is due to the fact that for these relations relativistic effects are numerically small.

In the relativistic quark model we obtained the following expressions for anomalous magnetic moments of the baryon octet [14]:

$$\mu_p^{an} = \frac{X_1}{3m} + \frac{Z_1}{3}\left(4\mu_u^{an} - \mu_d^{an}\right), \tag{1.1}$$

$$\mu_n^{an} = -\frac{Y_1}{3m} + \frac{Z_1}{3}\left(4\mu_d^{an} - \mu_u^{an}\right), \tag{1.2}$$

$$\mu_{\Sigma^+}^{an} = \frac{1}{3}\left[\frac{4X_2\frac{m+m_s}{2m} - X_3\frac{m}{m_s}}{2m+m_s} - \frac{2Y_2}{3m} + \frac{2Y_3}{3m_s}\right] + \frac{1}{3}\left(4Z_2\mu_u^{an} - Z_3\mu_s^{an}\right), \tag{1.3}$$

$$\mu_{\Sigma^-}^{an} = \frac{1}{3}\left[\frac{X_3\frac{m}{m_s} - 4X_2\frac{m+m_s}{2m}}{2m+m_s} + \frac{4Y_2}{3m} - \frac{Y_3}{3m_s}\right] + \frac{1}{3}\left[4Z_2\mu_d^{an} - Z_3\mu_s^{an}\right], \tag{1.4}$$

$$\mu_\Lambda = -\frac{Y_3}{6m_s} + Z_3\mu_s^{an}, \tag{1.5}$$

$$\mu_{\Sigma\Lambda} = \frac{Y_2}{2\sqrt{3}\,m} + \frac{Z_2}{\sqrt{3}}\left(\mu_u^{an} - \mu_d^{an}\right), \tag{1.6}$$

$$\mu_{\Xi^0} = -\frac{1}{9m_s}\left(2\tilde{Y}_2 + \frac{m_s}{m}\tilde{Y}_3\right) + \frac{1}{3}\left(4\tilde{Z}_2\mu_s^{an} - \tilde{Z}_3\mu_u^{an}\right), \tag{1.7}$$

$$\mu_{\Xi^-}^{an} = \frac{1}{3}\left[\frac{\frac{m_s}{m}\tilde{X}_3 - 4\tilde{X}_2\frac{m+m_s}{2m_s}}{} + \frac{4\tilde{Y}_2}{3m_s} - \frac{\tilde{Y}_3}{3m}\right] + \tag{1.8}$$

$$+ \frac{1}{3}\left(4\tilde{Z}_2\mu_s^{an} - \tilde{Z}_3\mu_d^{an}\right),$$

where m and m_s are $u(d)$ and s quarks masses, μ^{an}, μ_d^{an} and μ_s^{an} are their anomalous magnetic moments. The quantities X_i, Y_i, Z_i (i = 1, 2, 3) are equal to

$$X_i = \int \gamma_i \frac{|\phi(M_{0i}^2)|^2}{2M_{0i}/M_i^x}\, d\Gamma_i\,, \tag{2}$$

$$Y_i = \int \frac{\gamma_i}{\frac{3}{2}\eta_i}\, \frac{|\phi(M_{0i}^2)|^2}{2M_{0i}/M_i^y}\, d\Gamma_i\,, \quad Z_i = \int \beta_i |\phi(M_{0i}^2)|^2\, d\Gamma_i\,.$$

Here M_{0i} are invariant masses of the systems of quarks composing baryons; $\phi(M_{0i}^2)$ are baryon wave functions which as in Refs. [12-14] we shall write down in the form:

$$\phi(M_{0i}^2) = N\exp\left(-\frac{M_{0i}^2}{\alpha_i^2}\right). \tag{3}$$

The quantities γ_i, η_i, β_i, M_i^x, M_i^y are defined in Appendix. $\tilde{X}_i$, $\tilde{Y}_i$ and $\tilde{Z}_i$ (i =2, 3) can be obtained from X_i, Y_i and Z_i by replacements $m \rightleftarrows m_s$. The values of X_i, Y_i, Z_i (i =1, 2, 3) depend on the quark effective momenta in baryons which are defined by parameters α_i. In the nonrelativistic limit ($\alpha_i \to 0$) $X_i = Y_i = Z_i = 1$

We obtained in Refs. [12, 13] sufficiently rigid estimates for mean-square momenta of quarks in nucleon, for mass and anomalous magnetic moments of and d quarks.

$$\alpha_1 = 379 \pm 61 \text{ MeV}, \quad m = 271 \pm 28 \text{ MeV}, \quad \mathcal{H}_u^{an} = 0.012 \pm 0.030, \quad \mathcal{H}_d^{an} = -0.059 \pm 0.020, \tag{4}$$

where $\mathcal{H}_{u,d}^{an} = 2m\,\mu_{u,d}^{an}$.

With strange baryons included into the consideration some new free parameters arise due to the possible SU(3)–breaking effects: mass, anomalous magnetic moment of strange quark and parameters α_i characterizing the effective quark momenta in baryons which may be different for N , Λ , Σ and Ξ°.

We tried different mechanisms of the SU(3)–breaking in the baryon wave function (3). The best description of the experimental data has been obtained under the simple assumption that the dimensionless parameters $\beta_i \equiv \alpha_i/\bar{m}$ (where $\bar{m} = \frac{1}{3}\sum_q m_q$) are the same for all baryons from the octet:

$$\beta_N = \beta_\Sigma = \beta_\Lambda = \beta_\Xi \qquad (5)$$

The quantitative analysis we have done using the least square fit. In the case of Λ and Ξ° hyperon magnetic moments which have been measured with very high precision we took 3% errors instead of the experimental ones thus taking into account the theoretical uncertainty due to assumptions done.

The free parameters m_s and $\varkappa_s$ under the assumptions (5) turned out equal to

$$m_s = 450 \pm 32 \text{ MeV}, \qquad (6)$$

$$\varkappa_s^{an} = 0.058 \pm 0.04 .$$

It is very interesting that the obtained value of m_s agrees well with hadron mass splitting, for instance, the Lipkin relation [15]

$$m_s - m_u = M_\Lambda - M_p \qquad (7)$$

holds at the level of a few percents. At the same level we have

$$\varkappa_s^{an} = \varkappa_d^{an} . \qquad (8)$$

However one must keep in mind that the value of $\varkappa_s$ is badly defined and Eq.(8) may be strongly violated. Nevertheless it is interesting that in the framework of relativistic quark model the SU(3)–symmetry is not violated

for dimensionless quantities β and $\varkappa$ and all SU(3)–breaking effects can be taken into account using experimental hadron mass splitting (7).

From Eq.(5) it follows that the SU(3)–symmetry is badly broken for α_i and effective quark momenta in the strange baryons, especially in the Ξ hyperons, are higher than in nucleon.

The results are presented in the Table , where we have given also the values of the nucleon magnetic moments obtained in our previous works [12, 13]. The values of χ^2 given in brackets correspond to the experimental errors. For comparison we have given in the Table the results of the other works [4-6] based on the different modifications of a nonrelativistic quark model as well as the predictions of a naive quark model, the magnetic moments of p , n and Λ being used as input.

One can see from the Table that our results for all magnetic moments of the baryon octet are in excellent agreement with the experimental data excluding the $\Sigma^\circ \to \Lambda\gamma$ transition magnetic moment which turned out nearly by two standard deviations lower than the experimental value. Emphasize that the low value of $\mu_{\Sigma\Lambda}$ is peculiar to all quark model analyses. It is worth noting that in our analysis the values of μ_{Σ^-} , μ_{Ξ° and μ_{Ξ^-} are well described within the experimental errors, whereas in the other models it turned out possible to describe only one of these quantities.

Note that it seems impossible to describe the experimental value of $\mu_{\Sigma\Lambda}$ in the framework of our model as it is unreasonable to assume that Λ and Σ hyperon wave functions may differ strongly and therefore we have no additional free parameter. Note in this connection that the $\Sigma^\circ \to \Lambda\gamma$ transition magnetic moment, as distinct from the baryon magnetic moments measured with high precision, has been obtained in an indirect way making use of the Primakoff effect in the reaction $\Lambda^\circ + Z \to \Sigma^\circ + Z$ [16].

In the process of such type a problem arises in the isolation of the Coulomb amplitude from strong coherent production amplitude and hence the systematic errors may be large. Therefore a more precise experimental definition of the $\Sigma^{\circ} \to \Lambda\gamma$ transition magnetic moment seems highly important.

Thus, summing up the results of this analysis and the results of our previous work on the nucleon static characteristics we have in the framework of the relativistic quark model a consistent description of the baryon magnetic moments, electromagnetic radii and G_A/G_V ratio for nucleon.

APPENDIX

The values of γ_i, η_i, β_i, M_i^x and M_i^y, entering the integrands of expressions (2) have the following form:

$$\gamma_i = 2\,\frac{\eta_i(1-\eta_i)\mathcal{M}'^2_{oi} + \eta_i m_i M_{oi} - \frac{1}{2}\vec{Q}^2_{i\perp}}{\vec{Q}^2_{i\perp} + [m_i + (1-\eta_i)M_{oi}]^2}\,,$$

$$\eta_i = \frac{E^i_{ab} + Q_{i3}}{E^i_{ab} + E^i_c}\,, \quad \beta_i = 1 - \frac{\vec{Q}^2_{i\perp}}{\vec{Q}^2_{i\perp} + [m_i + (1-\eta_i)M_{oi}]^2}\,,$$

$$M_{oi} = E^i_{ab} + E^i_c\,, \qquad M^i_{ab} = \varepsilon^a_i + \varepsilon^b_i\,,$$

$$E^i_c = \sqrt{\vec{Q}^2_i + m^2_i}\,, \qquad E^i_{ab} = \sqrt{\vec{Q}^2_i + (M^i_{ab})^2}\,,$$

$$\varepsilon^a_i = \sqrt{\vec{q}^{\,2}_i + m}\,, \quad \varepsilon^b_2 = \sqrt{\vec{q}^{\,2}_2 + m^2_s}\,, \quad \varepsilon^b_1 = \sqrt{\vec{q}^{\,2}_1 + m^2}\,, \quad \varepsilon^b_3 = \sqrt{\vec{q}^{\,2}_3 + m^2}\,,$$

$$m_1 = m_2 = m\,, \qquad m_3 = m_s\,,$$

$$M^x_1 = M^y_1 = M^y_2 = 3m\,, \qquad M^x_2 = (2m + m_s)\,\frac{2m}{m + m_s}\,,$$

$$M^x_3 = (2m + m_s)\,\frac{m_s}{m}\,, \qquad M^y_3 = 3m_s\,.$$

The phase space $d\Gamma_i$ is equal to

$$d\Gamma_i = \frac{M^i_{ab}}{2\varepsilon^a_i\varepsilon^b_i}\;\frac{M_{oi}}{2E^i_{ab}E^i_c}\;\frac{d\vec{q}_i\,d\vec{Q}_i}{(2\pi)^6}\,.$$

Table

Particles	Our results	Naive quark model	Isgur and Karl [4]	Singh [5]	Bohm, Huerta and Zepeda [6]	Experiment
P	2.811 [12, 13]	2.793 (input)	2.85	2.79	2.83	2.793 [3]
n	-1.848 [12, 13]	-1.913 (input)	-1.85	-1.91	-1.78	-1.913 [3]
Λ	-0.613 $(x^2=0.00)$	-0.613 (input)	-0.61	-0.608	-0.58	-0.6129±0.0045 [1]
Σ^+	2.457 $(x^2=1.00)$	2.67	2.54	2.37	2.72	2.33±0.13 [3]
Σ^-	-1.236 $(x^2=0.46)$	-1.09	-1.00	-0.99	-1.15	-1.41±0.25 [3]
Ξ°	-1.251 $(x^2=0.00)$	-1.44	-1.20	-1.22	-1.37	-1.250±0.014 [1]
Ξ^-	-0.738 $(x^2=0.02)$	-0.49	-0.43	-0.48	-0.63	-0.75±0.07 [2]
$\Lambda\Sigma^\circ$	1.401 $(x^2=5.44)$	-1.63	-1.51	1.50	-1.54	$1.82^{+0.25}_{-0.18}$ [16]

References

1. P.T.Cox, J.Dworkin, O.E.Overseth et al. Precise Measurement of the Ξ° Magnetic Moment. Phys.Rev.Lett.,1981,vol.46, N.14,p.877-880.
2. T.Delvin, Bull.Ann.Phys., 80C, 1980, 572.
3. Review of Particle Properties, Rev.of Mod.Phys., vol.52,1980
4. N.Tsgur,G.Karl. Ground State Baryon Magnetic Moments, Phys.Rev.,1980,V.D21,N.11, p.3175-3179.
5. C.P.Singh. Magnetic Moments of Baryons, Phys.Rev., 1981, vol.D23,N.9,p.2085-2086.
6. M.Böhm, R.Huerta, A.Zepeda, Spin-Dependent Quark-Quark interaction and Baryon Magnetic Moments. Phys.Rev.,1982, vol.D25, N.1, p.223-234.
7. H.J.Lipkin. Model-Independent Analysis of Experimental Baryon Magnetic Moments. Phys.Rev.,1981,vol.D24,N.5, p.1437-1440.
8. M.V.Terentyev. On the Structure of the Wave Functions of mesons as of Bound States of Relativistic Quarks. Yad.Fiz. 1976,vol.24,N.1, p.207-213; Mesons Composed of Relativistic Quarks. Preprint ITEP,N.6,1976.
9. V.B.Berestetsky, M.V.Terentyev. Light-Front Dynamics and the Nucleons Made of Relativistic Quarks.Yad.Fiz.,1976, vol.24,N.5,p.1044-1057.
10. V.B.Berestetsky, M.V.Terentyev. Nucleons from Factors and Dynamics of the Light Front. Yad.Fiz.,1977,V.25,N.3, p.653-665.

11. L.A.Kondratyuk, M.V.Terentyev. Scattering Problem for Relativistic Systems with a Fixed Particle Number in the Light-Front Dynamics, Yad.Fiz.,1980,V.31,N.4,p.1087-1106.
12. I.G.Aznauryan, A.S.Bagdasaryan, N.L.Ter-Isaakyan. Relativistic Quark Model in Infinite Momentum Frame and Static Properties of Nucleons. Phys.Lett.,1982,vol.111B.
13. I.G.Aznauryan, A.S.Bagdasaryan, N.L.Ter-Isaakyan. Relativistic Quark Model in Infinite Momentum Frame and Static Properties of Hadrons. Preprint EFI-550(37)-82.
14. I.G.Aznauryan, N.L.Ter-Isaakyan. Anomalous Magnetic Moments of Quarks in Magnetic Dipole Transitions of Hadrons. Yad.Fiz.,1980,V.31,N.6,p.1680-1689.
15. H.J.Lipkin, Magnetic Moments,Hadron Masses, and Quark Masses. Phys.Rev.Lett.,1978, vol.41,N.24, p.1629-1631.
16. F.Dudak, F.L.Navarria, O.E.Overseth et al., Measurement of the Σ^0 Lifetime, Nucl.Phys.,1977,vol.B118,N.1/2,p.1-24.

The manuscript was received 20 April, 1982

И.Г.АЗНАУРЯН, А.С.БАГДАСАРЯН,
Н.Л.ТЕР-ИСААКЯН

МАГНИТНЫЕ МОМЕНТЫ ОКТЕТА БАРИОНОВ В РЕЛЯТИВИСТСКОЙ
КВАРКОВОЙ МОДЕЛИ
(на английском языке, перевод З.Н.Асланян)
Ереванский физический институт

Редактор Л.П.Мукаян
Тех.редактор А.С.Абрамян

Заказ 2II ВФ-03808 Тираж 299

Препринт ЕФИ Формат издания 60х84/I6
Подписано к печати 25/У-82 0.9 уч.-изд.л. Ц. I4 к.

Издано Отделом научно-технической информации
Ереванского физического института, Ереван-36, Маркаряна 2