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MAGNETIC MOMENTS OF BARYONS AND STRANGE CONTENT OF THE NUCLEON

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INTRODUCTION AND SUMMARY OF SUM RULE APPROACH TO $\mu(B)$

The presently available precise data on hyperon magnetic moments [1, 2, 3] may be the basis of new,more subtle and detailed information on the internal structure of baryons,e.g.,the strangeness content of the nucleon (see,e.g. [4] and references therein).The main emphasis of this work is put on the role of nonvalence degrees of freedom – the sea partons and/or the peripheral meson clouds ,which should be reflected in any approach tending to be adequate to the achieved experimental accuracy.With these aims in view,we present, in this report,some consequences of sum rules which follow from the theory of broken internal symmetries and a particular parametrization of contributions due to nonvalence degrees of freedom to the baryon magnetic moments. In [5, 6], the following parametrization was introduced for magnetic moments $\mu(B)$ of baryons $(B = q_e^2 q_o,\ q_e = q_{even},\ q_o = q_{odd},\ B = P, N, \Sigma, \Xi)$:

$$\mu(B) = \mu(q_e)g_2 + \mu(q_o)g_1 + C(B) + \Delta, \tag{1}$$

$$\mu(\Lambda) = \mu(s)(\frac{2}{3}g_2 - \frac{1}{3}g_1) + (\mu(u) + \mu(d))(\frac{1}{6}g_2 + \frac{2}{3}g_1) + \Delta, \tag{2}$$

$$\mu(\Lambda\Sigma) = \frac{1}{\sqrt{3}}(\mu(u) - \mu(d))(\frac{1}{2}g_2 - g_1) + C(\Lambda\Sigma), \tag{3}$$

$$\Delta = \sum_{q=u,d,s} \mu(q)\delta(N), \tag{4}$$

where $\mu(q)$ are the effective quark magnetic moments defined without any non-relativistic approximations, $g_{2(1)}$ are "reduced" dimensionless coupling constants obeying exact $SU(3)$-symmetry, $\delta(B)$ is a matrix element of the OZI-suppressed $\overline{q}q$-configuration for a given hadron: $\delta(B) =< B|\overline{q}q|B >$, where $q \not\subset \{q_e^2, q_o\}$, e.g. $\delta(N) =< N|\overline{s}s|N >$, etc., $C(P) = -C(N)$ and $C(\Lambda\Sigma)$ are the isovector contributions of the charged-pion exchange current to $\mu(P), \mu(N)$ and the $\Lambda\Sigma$-transition moment $\mu(\Lambda\Sigma)$. Below, we shall use the particle and quark symbols **for the corresponding magnetic moments. Equations (1) — (4) lead to the following sum rules** [5, 6] :

$$P + N + \Xi^0 + \Xi^- - 3\Lambda + \frac{1}{2}(\Sigma^+ + \Sigma^-) = 0, \tag{5}$$

$$(\Sigma^+ - \Sigma^-)(\Sigma^+ + \Sigma^- - P - N) - (\Xi^0 - \Xi^-)(\Xi^0 + \Xi^- - P - N) = 0, \tag{6}$$

$$\alpha = \frac{D}{F+D} = \frac{g_2 - 2g_1}{2(g_2 - g_1)} = \frac{1}{2}\left(1 - \frac{\Xi^0 - \Xi^-}{\Sigma^+ - \Sigma^- - \Xi^0 + \Xi^-}\right), \tag{7}$$

$$C(P) = \frac{1}{2}(C(P) - C(N)) = \frac{1}{2}(P - N + \Xi^0 - \Xi^- - \Sigma^+ + \Sigma^-), \tag{8}$$

$$C(\Lambda\Sigma) = \mu(\Lambda\Sigma) + \frac{1}{\sqrt{3}}(\Xi^0 - \Xi^- - \frac{1}{2}(\Sigma^+ - \Sigma^-)), \tag{9}$$

$$\frac{u-d}{u-s} = \frac{\Sigma^+ - \Sigma^- - \Xi^0 + \Xi^-}{\Sigma^+ - \Xi^0}, \tag{10}$$

$$\frac{u}{d}=\frac{\Sigma^+(\Sigma^+-\Sigma^-)-\Xi^0(\Xi^0-\Xi^-)}{\Sigma^-(\Sigma^+-\Sigma^-)-\Xi^-(\Xi^0-\Xi^-)}, \quad (11)$$

$$\frac{s}{d}=\frac{\Sigma^+\Xi^- - \Sigma^-\Xi^0}{\Sigma^-(\Sigma^+-\Sigma^-)-\Xi^-(\Xi^0-\Xi^-)}, \quad (12)$$

$$\Delta^{++}=\frac{u}{s}\Omega^-=\frac{u}{d}\Delta^{--}. \quad (13)$$

Reserving the possibility of $g_i(N)\neq g_i(Y), Y=\Lambda,\Sigma,\Xi$, due to a more prominent role of the pion degrees of freedom in the nucleon and combining Eqs. (5)-(6), we propose also the following, probably, most general sum rule of this approach

$$(\Sigma^+-\Sigma^-)(\Sigma^++\Sigma^--6\Lambda+2\Xi^0+2\Xi^-)$$
$$-(\Xi^0-\Xi^-)(\Sigma^++\Sigma^-+6\Lambda-4\Xi^0-4\Xi^-)=0. \quad (14)$$

Eqs. (11) - (13) are obtained provided $\delta(N)=0$. Hence,we relate them with the chiral constituent quark models, where we assume the validity of the OZI (or the quark-line) rule. Eq.(14) should be valid provided the Λ - value is "refined" from the e.m. $\Lambda\Sigma$ - mixing effects,therefore it can be used for evaluation of the corresponding $\Lambda\Sigma$ - mixing angle [6, 7]: $\theta^{e.m.}_{\Lambda\Sigma}=(1.43\pm.31)10^{-2}$. Equation (11) shows that owing to an interaction of the constituent u- and d-quarks with charged pions the "magnetic anomaly" appears, i.e. $u/d=-1.80\pm0.02\neq Q_u/Q_d=-2$. Evaluation of the lowest order quark-pion loop diagrams gives [6]: $u/d=(Q_u+\kappa_u)/(Q_d+\kappa_d)=-1.77$, where κ_q is the quark anomalous magnetic moment in natural units. For more detailed parametrization of the pion exchange current contributions to Eqs.(8)-(9) and to the transition operators $\mu(\Delta^+P)=\mu(\Delta^0N)$ and $\mu(\Sigma^{*0}\Lambda)$ we assume [7],by the analogy with nuclear physics,

$$\hat{\mu}_{exch}=\sum_{i<j}[\vec{\sigma}_i\times\vec{\sigma}_j]_3[\vec{\tau}_i\times\vec{\tau}_j]_3 f(r_{ij}), \quad (15)$$

for the quark-pion exchange magnetic moment operator,where $\vec{\sigma}_i(\vec{\tau}_i)$ are spin (isospin) operators of quarks, $f(r_{ij})$ is the known, within the specified models, function of the interquark distances,(e.g. [8]). Calculating the matrix elements of $\hat{\mu}_{exch}$ between the baryon wave functions, belonging to the 56-plet of $SU(6)$, one can find

$$C(P)=\frac{1}{\sqrt{2}}C(\Delta^+P)=\sqrt{3}C(\Lambda\Sigma), \quad (16)$$

$$\mu(\Delta^+P;\{56\})=\frac{1}{\sqrt{2}}\left(P-N+\frac{1}{3}(P+N)\frac{1-u/d}{1+u/d}\right). \quad (17)$$

where Eq.(17) may serve as a generalization of the well-known $SU(6)$-relation [9, 10]. Repeating the calculations of [8] with the explicit (gaussian) radial wave functions, we find that a needed numerical value of C(P), Eq.(8), is obtained with the oscillator parameter giving the radius $<r^2>^{\frac{1}{2}}=0.5$ fm for the quark "core" of

the nucleon. We close this section presenting the set of sum rules following from Eqs.(1)-(4) with C(B's) =δ(B's) = 0:

$$\Sigma^+[\Sigma^-]=P[-P-N]+(\Lambda-\frac{N}{2})(1+\frac{2N}{P}), \quad (18)$$

$$\Xi^0[\Xi^-]=N[-P-N]+2(\Lambda-\frac{N}{2})(1+\frac{N}{2P}), \quad (19)$$

$$\mu(\Lambda\Sigma)=-\frac{\sqrt{3}}{2}N, \quad (20)$$

The numerical values of Eqs.(18)—(19) coincide almost identically with the results of the $SU(6)$—based NRQM taking account of the $SU(3)$ breaking due to the quark-mass differences [11].We stress,however,that no NR assumption or explicit $SU(6)$-wave function are used this time. In calculations we used baryon magnetic moments from the PDG-tabulation [1] except $\mu(\Xi^-)$ and $\mu(\Sigma^+)$, from [2] and [3],respectively.

OZI RULE VIOLATION IN MAGNETIC COUPLINGS OF BARYONS

Here we follow a complementary view of the nucleon structure, absorbing C(N's) into g(N's),keeping the constraint u/d=-2,and $\delta(B's)$ non-zero. We shall refer to this approach [12] as a correlated current quark picture of nucleons.Then,instead of Eq.(11) we have (in n.m.)

$$\Delta(N)=\frac{1}{6}(3(P+N)-\Sigma^++\Sigma^--\Xi^0+\Xi^-)=-.07\pm.01, \quad (21)$$

$$\mu_N(\bar{s}s)=\mu(s)<N|\bar{s}s|N>=(1-\frac{d}{s})^{-1}\Delta=.13, \quad (22)$$

where the ratio d/s=1.55 from the correspondingly modified Eq.(12) is used. By definition, $\mu_N(\bar{s}s)$ represents the contribution of strange ("current") quarks to nucleon magnetic moments.Numerically, Eq.(22) agrees fairly well with other more specific models (see,e.g. [13]). The calculated quantity indicates violation of the OZI rule and the strange quark contribution $\mu_N(\bar{s}s)$ is seen to constitute a sizable part of the isoscalar magnetic moment of nucleons

$$\frac{1}{2}(P+N)=\mu(\bar{u}u+\bar{d}d)+\mu(\bar{s}s)=.44, \quad (23)$$

This observation helps to understand the unexpectedly large ratio [14]

$$BR\left(\frac{\overline{P}N\to\phi+\pi}{\overline{P}N\to\omega+\pi}\right)\simeq(10\pm2)\%, \quad (24)$$

reported for the s-wave $\bar{N}N$ - annihilation reaction.
Indeed,the transition $(\overline{P}N)_{s-wave}\to V+\pi$, where $V=\gamma,\omega,\varphi$, is of the magnetic dipole type.Therefore the transition operator should be proportional to the

isoscalar magnetic moment contributions from light u- and d-quarks and the strange s-quark,Eq.(22).The transition operators for the ω- and ϕ-mesons are obtained from $\mu(\overline{q}q)$ and $\mu(\overline{s}s)$ through the well-known vector meson dominance model (VDM).Using for the photon-vector-meson junction couplings the "ideal" mixing ratio $g_\omega : g_\phi = 1 : \sqrt{2}$ and $\mu_\omega : \mu_\phi = \mu(\overline{q}q) : \mu(\overline{s}s)$ according to Eqs.(22) and (23),we get

$$BR\left(\frac{\overline{P}N \to \phi + \pi}{\overline{P}N \to \omega + \pi}\right) \simeq \left(\frac{\mu(\overline{s}s)}{\sqrt{2}\mu(\overline{u}u + \overline{d}d)}\right)^2 \left(\frac{p_\phi^{c.m.}}{p_\omega^{c.m.}}\right)^3 \simeq 6\%, \qquad (25)$$

which is reasonably compared with data.
The structure constants connected with the vector part of the weak neutral current (NC) are obtained from the electromagnetic ones by the substitution

$$Q(q) \to V^{NC}(q) = t_L(q) - 2Q(q)\sin^2\theta_W, \qquad (26)$$

where Q(q) is the quark electric charge,t_L-the 3rd component of weak isospin, $sin^2\theta_W = .23$,θ_W-the weak angle.In this way we get for the NC analogue of magnetic moments of the proton,neutron and deuteron (in the units of n.m.):

$$\mu^{NC}(P) \simeq 1.293(1.067), \qquad (27)$$
$$\mu^{NC}(N) \simeq -1.248(-1.474), \qquad (28)$$
$$\mu^{NC}(d) \simeq .04(-.41), \qquad (29)$$

where values in the parentheses refer to the neglect of the strange quark contributions. Therefore the planned detailed investigation of the $\gamma - Z^0$ interference effects and measuring $\mu_N(\overline{s}s)$ via the P- odd effects in polarized electron-nucleon scattering [13] will give an important information on the strangeness content of the nucleon.
The value of $< N|\overline{s}s|N >$ in Eq.(22) can be considered as the difference of the averaged values $< N|l_z(s)+\sigma_z(s)|N >$ of strange quarks and,respectively,antiquarks, $l_z(s)$ and $\sigma_z(s)$ being the orbital and spin operators of corresponding quarks in the polarized nucleon.Taking,for the sake of qualitative estimates, $\mu(s) = -e/(6\epsilon_s) \simeq -.7$ n.m.,where we put $\epsilon_s \simeq (m_s^2 + p_s^2)^{\frac{1}{2}}$, $m_s(\simeq 150MeV)$ - the "current" quark mass,$p_s(\simeq 400MeV)$-the mean momentum of sea quarks, we obtain $< N|\overline{s}s|N > \simeq -.17$, which can be compared with the other strange quark spin characteristics $\Delta s \simeq -.1$, as given by the polarized DIS data, e.g. [15]

CONCLUSIONS AND REMARKS

1.The deviation of the ratio $F/D = .75$,Eq.(7), from the $SU(6)$ -value 2/3 and more detailed analysis of a set of sum rules carried out in [7] show,that despite the validity of the celebrated $SU(6)$-ratio [9, 10] $\mu(P)/\mu(N) = -3/2$,the $SU(6)$-symmetry is strongly broken.Its breaking may be effective in nucleons and weak in Δ's [7],giving evidence of the instanton-induced,spin-dependent qq-interaction [16] which posesses the required properties.

2.The real meaning of all failures (and relative successes,of course) of the "naive" NRQM results (e.g.[11]) ,coinciding with values from Eq.(18)-(20),is the neglect of contributions due to the nonvalence degrees of freedom (the sea partons and/or meson clouds at the periphery of hadrons).
3.The strange current quarks considered as a part of the constituent quark internal structure should be explored by the probes with the resolution capability comparable with the constituent quark size,i.e. in the processes with high enough momentum transfers or the energy release:
4. The "strange" content of the nucleon may also include, in addition to the strange $\overline{s}s$-quarks,some admixture of valence gluons [17],which could help to understand the different F/D - ratios following from the magnetic moment and semileptonic hyperon decay analyses [7]. This would be most natural if the dominant-hybrid nucleon resonance had not so large mass,e.g.,in the region of the Roper resonance (or resonances) around $M_R \simeq 1450$ MeV.
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Магнитные моменты барионов и скрытая странность нуклона

Феноменологический подход, основанный на применении правил сумм, используется для обсуждения зависимости некоторых электрослабых статических характеристик нуклонов от их кваркового содержания. Показана важность учета невалентных степеней свободы (партонов моря и/или мезонных токов на периферии нуклонов) для адекватного выбора и параметризации наблюдаемых величин на основе внутренних симметрий. Отмечено влияние присутствия странных кварков в нуклоне на величину нарушения правила Окубо — Цвейга — Иизуки в реакциях нуклон-антинуклонной аннигиляции. Отмечены и обсуждены некоторые другие следствия общего подхода на основе правил сумм для электрослабых констант связи барионов.

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Magnetic Moments of Baryons and Strange Content of the Nucleon

The phenomenological sum—rule—based approach is used to discuss the quark composition dependence of some static electroweak characteristics of nucleons. The role of nonvalence degrees of freedom (the nucleon sea partons and/or peripheral meson currents) is shown to be important to select and make use of the relevant symmetry parametrization of hadron observables. The implication of hidden strangeness of the nucleon for the recently observed OZI-rule violation in antinucleon-nucleon annihilation reactions is pointed out. Some further consequences of a general sum rule approach to baryon electroweak coupling constants are presented and discussed.

The investigation has been performed at the Bogoliubov Laboratory of Theoretical Physics, JINR.

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