объединенный
институт
ядерных
исследований
дубна

E2-88-122

S.B.Gerasimov

MAGNENIC MOMENTS OF BARYONS AND RADIATIVE DECAYS OF LOWEST MESON RESONANCES

Submitted to the 8-th International Conference
on the Problems of Quantum Field Theory,
Alushta, USSR, October 10-16, 1987

1988

I. Introduction

The quark model calculations of magnetic moments and radiative decays of hadrons are known to provide a simple and clear understanding of the SU(3) - and SU(6)-symmetry predictions /1-3/, to locate a number of the unitary symmetry breaking effects in the hadron electromagnetic properties, and to enable an estimation of the effective (i.e.dynamical) masses of constituent quarks /4-6/. This paper is devoted to the consideration of hadron magnetic moments. A starting point is the phenomenological sum rules following from the general groundwork of many quark models including relativistic effects and nonadditive corrections due to the pion currents expected to be an important ingredient of the hadron peripheral structure. Inclusion of the mesonic (mainly, pionic) degrees of freedom into consideration is a common feature of the hybrid chiral models /7-10/, where both the quark and mesonic field variables enter into the effective interaction Lagrangian.

We apply to the sum rule techniques to obtain, at the price of a minimal number of the model-dependent assumptions, a more reliable, though not as much detailed information about the hadron properties in question.

2. Magnetic moments of baryons and quarks in broken SU(3)

We formulate an approach based both on the theory of broken unitary symmetries and composite quark models. First, the electromagnetic current operator of a quark system is assumed to be a sum of the relativistic covariant operators referring to single constituent quarks. The form of these currents in a configuration space is not specified. The magnetic moment operator is defined by the well-known moment of the total current, and we introduce the following notation for baryon magnetic moments through an additive sum of single quark operators:

$$\mu(B) = \sum_i \sum_q \mu(q_i) \langle B | \bar{q}_i q_i | B \rangle = \frac{1}{\sqrt{2}} \left(\mu(u) - \mu(d) \right) \langle B | \hat{\rho}_3 | B \rangle + \frac{1}{\sqrt{6}} \left(\mu(u) + \mu(d) - 2\mu(s) \right) \langle B | \hat{\omega}_8 | B \rangle + \frac{1}{\sqrt{3}} \left(\mu(u) + \mu(d) + \mu(s) \right) \langle B | \hat{\omega}_1 | B \rangle \qquad (1)$$

where

$$\hat{\rho}_3 = \frac{1}{\sqrt{2}}\sum_i(\bar{u}_i u_i - \bar{d}_i d_i) \quad ,$$
$$\hat{\omega}_8 = \frac{1}{\sqrt{6}}\sum_i(\bar{u}_i u_i + \bar{d}_i d_i - 2\bar{s}_i s_i), \qquad (2)$$
$$\hat{\omega}_1 = \frac{1}{\sqrt{3}}\sum_i(\bar{u}_i u_i + \bar{d}_i d_i + \bar{s}_i s_i) \quad .$$

Eqs.(1) and (2) define only the structure of the corresponding operators in the SU(3) internal variable space. No assumption about the nonrelativistic quark dynamics is made. Also, no constraints are made on magnitudes of $\mu(q)$ ($q = u, d, s$) absorbing the hadronic matrix element values of the vector currents, defined in terms of the quark dynamical configuration variables (momenta, spins, etc.). But the matrix elements over the octet baryon state of the $\hat{\rho}_3$, $\hat{\omega}_8$ and $\hat{\omega}_1$ which have explicit SU(3)-transformation properties will now be parametrized according to the unbroken SU(3). The inaccuracy thus introduced is expected to be of the same order as that of the SU(3)-parametrization for the axial current matrix elements in the Cabibbo theory. The above-mentioned approach, in turn, is known for a long time to be a good basis for the description of leptonic decays of octet baryons /11/ . We also take a simple parameterization scheme of the pion current contributions to baryon magnetic moments which is suggested by the simplest Feynman diagrams with the two-pion intermediate states in the current channel. Those diagrams, where the pion propagator line begins and ends on the same quark, are assumed to be absorbed in the quantities $\mu(q)$. The pion exchange current contributions are defined by the diagrams with the pion propagator connecting different quark lines. It is easy to visualize that the charged pion exchange currents contribute to magnetic moments of the proton, neutron and to the transition magnetic moment $\mu(\Sigma^0\Lambda)$ and will not contribute to $\mu(Y)$, where $Y=\Lambda,\Sigma,\Xi$. With the isotopic sum rule $\mu(\Sigma^0) = (\mu(\Sigma^+)+\mu(\Sigma^-))/2$ we have 7 measured values of $\mu(B)$: $B = P, N, \Lambda, \Sigma^{\pm}, \Xi^{0,-}$ and 7 free parameters: $\mu(q)$, $(q = u,d,s)$, $\langle B|\hat{\rho}_3(\hat{\omega}_8)|B\rangle$ – two constants of F- and D type, $C^P_{exch} = \langle B|\hat{\mu}^{\pi}_{exch}|P\rangle = -\langle N|\hat{\mu}^{\pi}_{exch}|N\rangle$ and $\langle B|\hat{\omega}_1|B\rangle$.

Analysis of the obtained system of equations shows that it is a degenerate one. Due to this fact the following two sum rules turn out to be valid at any values of free constants:

$$P + N + \Xi^0 + \Xi^- - 3\Lambda - \tfrac{1}{2}(\Sigma^+ + \Sigma^-) = 0 \quad , \qquad (3)$$

$$(\Sigma^+ - \Sigma^-)(\Sigma^+ + \Sigma^- - P - N) - (\Xi^0 - \Xi^-)(\Xi^0 + \Xi^- - P - N) = 0 . \qquad (4)$$

All particle symbols in Eqs. (3) and (4) and further on denote the corresponding magnetic moments in nuclear magnetons. Note that sum rules (3) and (4), taken separately, have been considered, correspondingly, in Refs. /12/ and /13/ , though from points of view completely different from ours.

The following features of the present experimental situation are most important for us. We use for numerical estimates the value $\Sigma^- = -1.164 + 0.014$ which is the weighted average of the last three most accurate measurements /14/ . Two measurements of the Σ^+ - hyperon magnetic moment in similar experiments gave the following values: $\Sigma^+ = 2.379 + 0.02$ /15/ and $\Sigma^+ = 2.479 + 0.025$ /16/ (we expose here the mean-square root of the sum of statistical and systematic uncertainties). We single out Σ^+ and Ξ^- as less reliably measured quantities and define them as solutions of Eqs.(3) and (4) in terms of other magnetic moments. For P , N and Ξ^0 we take the PDG-tabulated values /17/: $P = 2.793$; $N = -1.913$, $\Xi^0 = -1.250 + 0.014$. For the Λ -hyperon we examine two possibilities - (a): $\Lambda = -0.613 \pm 0.005$ - the tabulated value, and (b): $\Lambda = -0.58 \pm 0.01$ - following from the experimental value with an additional contribution due to the isospin-breaking $\Sigma^0\Lambda$ mixing being subtracted /18/ (it is just this quantity which should, by its physical meaning, enter into the sum rule (3)). As a result, we get

$$\Sigma^+ = 2.37 \pm 0.04 \quad , \quad \Xi^- = -0.87 \pm 0.04 \qquad (5a)$$
$$\Sigma^+ = 2.46 \pm 0.04 \quad , \quad \Xi^- = -0.72 \pm 0.04 . \qquad (5b)$$

Taking into account the experimental value /17/ $\Xi^- = -0.69 \pm 0.04$, we conclude that the sum rules (3) and (4) are in a much better agreement with the recent measurement /16/ - the case (5b). Within the formulated assumptions we also have

$$C^P_{exch} = \tfrac{1}{2}(P - N + \Xi^0 - \Xi^- - \Sigma^+ + \Sigma^-) = 0.25 \pm 0.02 , \qquad (6)$$

$$\alpha_D = D/(F+D) = \tfrac{1}{4}[3 - (P+N-\Sigma^+-\Xi^0)/(\Sigma^- - \Xi^-)] =$$
$$= \tfrac{1}{2}[1 - (\Xi^0 - \Xi^-)/(\Sigma^+ - \Sigma^- - \Xi^0 + \Xi^-)] = 0.566 \pm 0.022 , \qquad (7)$$

$$\frac{u-d}{u-s} = (\Sigma^+ - \Sigma^- - \Xi^0 + \Xi^-)/(\Sigma^+ - \Xi^0) = 1.127 \pm 0.012 , \qquad (8)$$

where u , d , s are the quark magnetic moments in nuclear magnetons.

For further convenience we introduce a new quantity

$$\lambda_m = \frac{2\langle N|\bar{s}s|N\rangle}{\langle N|\bar{u}u+\bar{d}d|N\rangle} \qquad (9)$$

and express $\langle B|\hat{\omega}_1|B\rangle$ through $\langle N|\hat{\omega}_8|N\rangle$ via

$$\langle B|\hat{\omega}_1|B\rangle = \sqrt{2}\cdot\frac{1+\lambda_m/2}{1-\lambda_m}\cdot\langle N|\hat{\omega}_8|N\rangle. \qquad (10)$$

We remind here that the bilinear quark field combinations in (9) denote, in fact, the corresponding moments of the vector current. The parameter λ_m can therefore be viewed as a characteristics of the quark content of nucleons tested by the vector probe. The λ_m may, in principle, differ in magnitude from a similar parameter λ_s perinent to the scalar probe. By this note we reserve a possible difference of λ_m from an unexpectedly large value of λ_s, which has recently attracted much attention in connection with problem of the σ -term in πN-scattering [19].

If we take $\lambda_m = 0$ according to a model of the valence quarks, then instead of (8) we get two more interesting relations

$$u/d = (P+N+\Sigma^+-\Sigma^-+\Xi^0-\Xi^-)/(P+N-\Sigma^++\Sigma^--\Xi^0+\Xi^-) = \qquad (11)$$

$$= [\Sigma^+(\Sigma^+-\Sigma^-)-\Xi^0(\Xi^0-\Xi^-)]/[\Sigma^-(\Sigma^+-\Sigma^-)-\Xi^-(\Xi^0-\Xi^-)] = -1.80 \pm 0.02,$$

$$s/d = (\Sigma^+\Xi^--\Sigma^-\Xi^0)/[\Sigma^-(\Sigma^+-\Sigma^-)-\Xi^-(\Xi^0-\Xi^-)] = 0.68 \pm 0.02. \qquad (12)$$

The dependence of Eqs. (11) and (12) on λ_m is depicted in Fig.1.

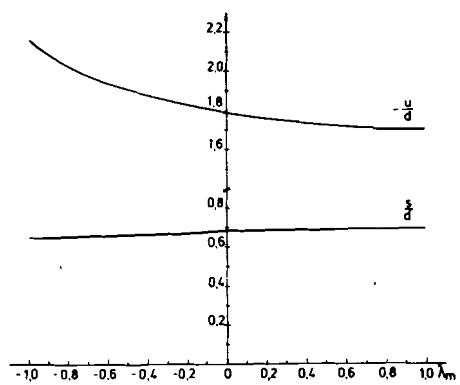

Fig.1

It is seen from there that u/d and s/d are weakly changed under variation of λ_m even within wide limits that have to be much larger than expected values of this quantity (it is relevant to remind a strong suppression of the φ -meson(predominantly $\bar{s}s$ - configuration) coupling to the nonstrange hadrons [20]).

The value (11) for u/d is in accord with earlier estimates [21-25]. The value (12) for s/d is, however, markedly higher than in Ref. [21] and, at the same time, lower as compared to [24,25]. The agreement of both (11) and (12) with the corresponding values of Ref. [23] appears to be a coincidence, because our approach is very different from that of ref. [23] (e.g., no exchange current contribution is taken into account in [23]). To get $\mu(\Sigma^0\Lambda) \equiv (\Sigma^0\Lambda)$ one should relate $C_{exch}^{\Lambda\Sigma^0}$ with C_{exch}^{P}. It seems sufficient to resort to a simplified consideration as far as the exchange contribution is not dominant. Therefore we represent the isovector operator $\hat{\mu}_{exch}^{\pi}$ of the exchange magnetic moment as a sum $\hat{\mu}_{exch}^{\pi} = \hat{\mu}(\underline{8}) + \hat{\mu}(\underline{10}^*-\underline{10})$ of two operators with the octet and decuplet transformation properties. Using, further, $C_{exch}^{Y} = 0$, $Y = \Sigma, \Xi$ and Eq. (6) we fix relations between 3 unknown constants parametrizing all matrix elements $\langle B|\hat{\mu}_{exch}^{\pi}|B\rangle$. In this way we get

$$C_{exch}^{\Sigma^0\Lambda} = \frac{1}{\sqrt{3}}\, C_{exch}^{P} \qquad (13)$$

which is also equivalent to the Okubo sum rule [2]:

$$2\sqrt{3}(\Sigma^0\Lambda) - 3\Lambda + \frac{1}{2}(\Sigma^+ + \Sigma^-) + 2N + 2\Xi^0 = 0. \qquad (14)$$

Substituting $\Lambda = -0.58 \pm 0.01$ and other magnetic moments into (14) we obtain: $(\Sigma^0\Lambda) = 1.51 \pm 0.02$ that lies within two standard deviations from the recently measured value: $|(\Sigma^0\Lambda)| = 1.60 \pm 0.07$ [26]. Assuming the universality hypothesis [4] of ratios (11) and (12) we get few experimentally testable relations for magnetic moments of the $J^P = 3/2^+$-decuplet baryons and transition magnetic moments $\mu(B_{10}^* \to B_8\gamma)$:

$$\mu(\Omega^-) = (s/u)\,\mu(\Delta^{++}) = -0.38\,\mu(\Delta^{++}) = -2.17 \pm 0.38 \qquad (15)$$

$$\mu(\Delta^-) = (d/u)\,\mu(\Delta^{++}) = -3.17 \pm 0.55 \qquad (16)$$

$$\mu(\Sigma^{*+}\to\Sigma^+\gamma):\mu(\Sigma^{*-}\to\Sigma^-\gamma):\mu(\Sigma^{*0}\to\Sigma^0\gamma):\mu(\Xi^{*0}\to\Xi^0\gamma)$$
$$:\mu(\Xi^{*-}\to\Xi^-\gamma) = 1 :-0.127 : 0.436 : 1 : -0.127. \quad (17)$$

The quantities $\mu(\Delta^+\to P\gamma)=\mu(\Delta^0\to N\gamma)$ and $\mu(\Sigma^{*0}\to\Lambda\gamma)$ contain the pion exchange contribution and additional (model-dependent) assumptions are required for their determination. To calculate (15) and (16) we have adopted /27/: $\mu(\Delta^{++}) = 5.7 \pm 1.0$.

3. Radiative meson decays

In treating the $V\to P\gamma$ and $P\to V\gamma$- decays the problem is to take properly into account the relativistic nonstatic retardation effects (i.e. the photon wave function variation over a distance of an order of the meson radii) and recoil effects (dependence of the radial overlap integrals on meson momenta). To minimize the dependence of final results on these effects, we confine ourselves to the comparison of the amplitude ratios for those processes which have close energies of final photons, e.g. $\omega\to\pi^0\gamma$ and $\rho\to\pi\gamma$, or $\rho\to\eta\gamma$ and $\eta'\to\rho\gamma$, etc. But even there one may hope to get only approximate cancellation of unknown dynamical factors. For a more accurate account of the momentum dependence of matrix elements, we propose to introduce the form factors $F(\vec{k}^2_{VP})$, where $|\vec{k}_{VP}| = (m^2_{V(P)} - m^2_{P(V)})/(2m_{V(P)})$. These form factors are assumed to enter into an additive (as to the quark counting) part of the considered (e.g. $V\to P\gamma$) matrix elements

$$\sum_i \langle P(\vec{k})|\hat{\mu}_i|V(\vec{0})\rangle = \sum_i F_i(\vec{k}^2)\langle P(\vec{0})|\hat{\mu}_i|V(\vec{0})\rangle \qquad (18)$$

and have been chosen of the following form:

$$F_{q(s)}(\vec{k}^2) = [1+\vec{k}^2/(2m^2_{\rho(\varphi)})]^{-2}, \quad q=u,d. \qquad (19)$$

To somehow justify the functional form of Eq. (19), we resort to the quark-hadron duality arguments. The radii of pseudoscalar mesons calculated in a model of the quark loops with consituent masses of quarks turn out to be close to the values /28/ following also from the vector dominance model (VDM). We have also derived the relation

$$R_{VDM} = (\langle r^2\rangle^{\pi^+} - \langle r^2\rangle^{K^+})/\langle r^2\rangle^{K^0} = -1 \qquad (20)$$

for the charge radii of π and K-mesons, easily verified with the standard VDM values

$$\langle r^2\rangle^{\pi^+}_{VDM} = 6m_\rho^{-2} \qquad (21)$$
$$\langle r^2\rangle^{K^+(K^0)}_{VDM} = \pm 3m_\rho^{-2} + m_\omega^{-2} + 2m_\varphi^{-2}$$

with the help of the well-known quantum-mechanical scale relations (e.g. /29/) for $\langle r^2\rangle$ in a nonrelativistic two-particle system with the power potential $V(r)\sim r^\nu$ where $\nu=-1$. The "dipole" dependence of $F=F(\vec{k}^2)$ in Eq. (19) corresponds just to the case of $\nu=-1$ that is to the behaviour of the form factor of a two-particle system with the effective Coulomb interaction at short distances. For numerical calculations of the $V\to P\gamma$ transitions according to Eq. (18) we shall, following the universality hypothesis /4/, make use of the quark moment relations found in the preceding section. Note that the exchange pion current contributes only to the isovector transitions: $\omega(\varphi)\to\pi^0\gamma$, $\rho\to\eta\gamma$, $\eta'\to\rho\gamma$. The isoscalar transitions ($\rho\to\pi\gamma$, $\omega\to\eta\gamma$, etc) and those between strange mesons ($K^*\to K\gamma$) are independent of the exchange contribution and there the $V\to P\gamma$ matrix elements have the following structure:

$$\langle P|\hat{\mu}^{\Delta I=0}|V\rangle = (\mu(u)+\mu(d))I^q_{VP}F_q(\vec{k}^2) + 2\mu(s)I^s_{VP}F_s(\vec{k}^2) \qquad (22)$$
$$\langle K|\hat{\mu}|K^*\rangle = [\mu(q)F_q(\vec{k}^2)+\mu(s)F_s(\vec{k}^2)]\cdot I_{K^*K}, \qquad (23)$$

where $q=u(d)$ for $K^{*+}\to K^+\gamma$ ($K^{*0}\to K^0\gamma$), I_{VP} is a static radial overlap integral. Two terms in Eq. (22) reflect a possibility of mixing in the isoscalar mesons of different (nonstrange and strange) quark configurations.

The isovector matrix elements will be parametrized simply by

$$\langle P|\hat{\mu}^{\Delta I=1}|V\rangle = [\mu(u)-\mu(d)+C_{exch}]\cdot I^q_{VP}F_q(\vec{k}^2), \qquad (24)$$

where C_{exch} is a unique constant for all transitions approximately representing the exchange pion contributions. It should be noted that even for mesons with the same quark contents (for example, K and K^*, or π and ρ) $I_{VP}\neq 1$ due to the spin-dependent $\bar{q}q$ -interactions that are different in V and P -mesons.

We have mentioned that the quark structure of isoscalar mesons may be a complex mixture of the $\bar{q}q$ -pairs of different flavours, i.e. the $(\bar{u}u+\bar{d}d)/\sqrt{2}$ and $\bar{s}s$ - configurations. This mixing is essentially different in pseudoscalar (η , η') and vector (ω, φ) mesons. It is well known that almost ideal separation of the strange and nonstrange quark configurations is realized in vector mesons. Physical state vectors of the ω and φ -mesons take therefore the form

$$\omega = N\cos\delta + S\cdot\sin\delta$$
$$\varphi = -S\cos\delta + N\cdot\sin\delta\,, \tag{25}$$

where $N=(\bar{u}u+\bar{d}d)/\sqrt{2}$, $S=\bar{s}s$, $\delta=\theta_0-\theta_V$ ($|\sin\delta|\ll 1$)

θ_V is angle of singlet-octet mixing in a vector nonet, θ_0 =35.26^0 is the ideal-mixing angle. The radial parts of the N (or S) quark configurations are assumed to be defined without taking into account the annihilation interaction that mixes the $\bar{u}u$, $\bar{d}d$ and $\bar{s}s$ - pairs. This way of description of the quark annihilation and mixing effect can be justified only by the annihilation mixing being small in vector mesons. For pseudoscalar mesons, the spin--spin and annihilation interactions are equally essential and the mass operator should, therefore, be diagonalized with both the above mentioned interactions being simultaneously included. A clear, though simplified representation of the wave function structure is achieved by the radial configuration mixing (see e.g.[30,31]). For illustration, the form is given below of the η and η' -state vectors obtained via one of the simplest methods of the linear mass operator diagonalization over (maximally) constrained sets of the basis wave functions $\{N_i\}$ and $\{S_i\}$ corresponding to the "zero" approximation (with both the spin-spin and annihilation interaction turned-off):

$$\eta = 0.80\cdot N_0 - 0.22\,N_1 - 0.53\,S_0 + 0.16\,S_1 \tag{26}$$
$$\eta' = 0.57\,N_0 + 0.06\,N_1 + 0.81\,S_0 + 0.09\,S_1\,,$$

where $N(S)_{0;1}$ is the ground (or 1st radially-excited) state of the corresponding quark configuration taken in the "zero" approximation. The η and η' wave functions in Eq. (26) cannot clearly be presented in a form including the orthogonal 2x2 matrix of mixing, analogous to Eq. (25).

The explicit form of (26) is also different from another popular representation of the η and η' state vectors

$$\eta = X_\eta N + Y_\eta S + Z_\eta G \tag{27}$$
$$\eta' = X_{\eta'} N + Y_{\eta'} S + Z_{\eta'} G\,,$$

G being the pseudoscalar glueball state vector, and $X^2+Y^2+Z^2=1$. The parametrization (27) has recently been used in the $J/\psi \to VP$ decay analysis [32] with the following results: $|X_\eta|$ =0.63±0.06, $|Y_\eta|$= 0.88 ±0.14, $|X_{\eta'}|$ =0.36 ± 0.05, $|Y_{\eta'}|$ =0.72 ± 0.12.

Let us outline main original results of this section. The most reliable confirmation of universal ratios of the quark magnetic moments in mesons and baryons [4] follow from the calculated ratio of the K^* -meson radiative widths:

$$\frac{\Gamma(K^{*+}\to K^+\gamma)}{\Gamma(K^{*0}\to K^0\gamma)} = \left[\frac{(u/d)+(s/d)\cdot\tau}{1+(s/d)\cdot\tau}\right]^2 = \begin{cases} 0.38 \pm 0.03 \text{ (th.)} \\ 0.44 \pm 0.06\,, \text{[17,33]} \end{cases} \tag{28}$$

where $\tau = F_s(\vec{k}^2_{K^*K})/F_q(\vec{k}^2_{K^*K})$ and values of (11) and (12) have been used in calculation. As $\tau\to 1$ in (28) the theoretical and experimental ratios become still closer. A standard estimate of the nonstrange quark admixture in φ -meson results from comparison of the $\omega\to\pi^0\gamma$ and $\varphi\to\pi^0\gamma$ decay widths:

$$\tan^2(\theta_0-\theta_V) = \frac{\Gamma(\varphi\to\pi^0\gamma)}{\Gamma(\omega\to\pi^0\gamma)}\cdot\left(\frac{F_q(\vec{k}^2_{\omega\pi})}{F_q(\vec{k}^2_{\varphi\pi})}\right)^2\cdot\left(\frac{|\vec{k}_{\omega\pi}|}{|\vec{k}_{\varphi\pi}|}\right)^3 \tag{29}$$

Taking $\Gamma(\omega\to\pi^0\gamma)$ = 853 ± 49 keV [17] and $\Gamma(\varphi\to\pi^0\gamma)$ =5.5±0.6 keV[34] and comparing our result with the earlier estimate [34], we find that inclusion of the form factor ratio in (29) shifts $\delta=\theta_0-\theta_V=-3^0$ cited in [34], to the value $\delta\simeq-3.5^0$ giving θ_V = 38.8^0 quite close to the angle following from the quadratic Gell-Mann-Okubo mass formula for vector mesons (for Γ ($\omega\to\pi^0\gamma$)=731±41 keV[35] we find δ =-3.8^0±0.2^0). With Eqs.(22),(24) and pertinent kinematical factors we get

$$\left(\frac{u-d+C_{exch}}{u+d}\right)^2 = 0.95\,\frac{\Gamma(\omega\to\pi^0\gamma)}{\Gamma(\rho\to\pi\gamma)} \tag{30}$$

With Γ ($\omega\to\pi^0\gamma$) from[17] or[35], Γ ($\rho\to\pi\gamma$)=63±4 keV[36] and u/d according to (11)) an estimate $\frac{C_{exch}}{u-d}=0.02\pm0.04$ (-0.05 ± 0.04) follows. The value of C_{exch} entering into (24) does not exceed the existing experimental uncertainties and can, therefore, be neglected later on.

Relations between the $\rho(\omega)\to\eta\gamma$ and $\eta'\to\rho(\omega)\gamma$ decays are derived by complete analogy with Eq. (30). Using the experimental data [17]: $\Gamma(\rho\to\eta\gamma)=52\pm13$ keV and $\Gamma(\eta'\to\rho\gamma)=72\pm12$ keV as well as u/d from (11), we have, as a consequence

$$\Gamma_{th.}(\omega\to\eta\gamma) = 4.2\pm1.0\ \text{keV}$$
$$\Gamma_{th.}(\eta'\to\omega\gamma) = 6.4+1.1\ \text{keV} \qquad (31)$$

which is in good agreement with the data [17]: $\Gamma(\omega\to\eta\gamma)=2.9^{+2.5}_{-1.8}$ keV and $\Gamma(\eta'\to\omega\gamma)=6.5\pm1.5$ keV. At last, from the ratios of $\Gamma(\eta'\to\rho\gamma)$ and $\Gamma(\rho\to\eta\gamma)$, $\Gamma(\varphi\to\eta\gamma)$ and $\Gamma(\rho\to\eta\gamma)$, with no model-dependent assumption about the quark content of the η and η' -mesons, we obtain

$$|I^{q}_{\eta'\rho}/I^{q}_{\eta\rho}| = 0.78\pm0.12 \qquad (32)$$

$$|I^{s}_{\eta\varphi}/I^{q}_{\eta\rho}| = 0.80\pm0.11\,. \qquad (33)$$

It is very interesting to compare (32) and (33) with what has to be essentially the same parameters, if the parametrization (27) would be valid: $|X_{\eta'}|/|X_\eta| = 0.57\pm0.10$ and $|Y_\eta|/|X_\eta| = 1.32\pm0.24$, following from the J/ψ - decays [32]. The confrontation of these values describing the large momentum transfer processes, such as the $J/\psi\to VP$ decays, and those of Eq. (32) and (33) is more in line with the theoretically expected result, namely, that the coefficients X, Y, Z in (27) could not be universal and independent of the processes including η and η' just because the very functions N and S are not universal, that is $N_\eta \neq N_{\eta'}$ and $S_\eta \neq S_{\eta'}$. The same emerges also from the specific model consideration resulting in (26). A slight difference between $|Y_\eta|/|X_\eta|$ and (33) gives some evidence for the SU(3) violation in the $J/\psi\to VP$ amplitudes.

4. Discussion

Most close to ours are the so-called "model-independent" approaches based on the quark-model sum rules [13,38]. A number of difficulties noted in Refs. [13,38] have been resolved in our approach as follows. The isovector Coleman-Glashow sum rule

$$P - N + \Xi^0 - \Xi^- - \Sigma^+ + \Sigma^- = 0 \qquad (34)$$

considered in Ref. [13], is strongly violated due to the nonadditive exchange contribution C_{exch} to P and N. The sum rule proposed by Sachs [37] and discussed in Ref. [13]

$$\Sigma^+ - \Sigma^- + \Xi^0 - \Xi^- - 3(P+N) = 0 \qquad (35)$$

is also at variance with data. Eq. (35) was previously derived within the nonrelativistic quark model with the assumed "standard" relation $u/d = -2$. In our approach, as a matter of fact, Eq. (35) taken with the replacement $3(P+N)\to(P+N)(u-d)/(u+d)$ is a source for deriving the u/d -ratio. A marked difference of the magnetic moment for the given quark flavour, but residing in different baryons noted in Ref. [38], is explained by the action of all or one of the following factors: $C_{exch}\neq 0$, $u/d\neq -2$ and the SU(6)-breaking effect: $\alpha_D \neq \alpha_D(SU(6)) = 0.6$.

The principal results of our approach consist in fixing free parameters: u/d - Eq. (11), s/d - Eq. (12), C^P_{exch} - (6), α_D - (7) and two sum rules (3) and (4) which enable us to express any two of the baryon magnetic moments through others. We notice again that the value (5b) for Σ^+ is in better agreement with the latest of two available experiments [16]. The value (11) for u/d confirms an earlier conclusion [21] that there is a "magnetic anomaly" in light quarks. The nonadditive contribution of pion currents to nucleon magnetic moments is significant. This is in a qualitative agreement with results of other authors [10,25], though, quantitatively, our C^P_{exch} is twice as less as that, for example, in Ref. [10]. The direction of a small deviation of α_D from $\alpha_D(SU(6))$ is opposite to that found from the semileptonic hyperon decays [11]. This finding requires an independent check and interpretation. The study of asymmetries in deep inelastic scattering of polarized leptons on polarized nucleons could, probably, be a source of a relevant information. Universality of the quark magnetic properties including the strength of the SU(3) breaking in baryons and mesons [4] is confirmed by agreement of the computed and measured ratios of the $K^*\to K\gamma$ radiative decays [17,33]. The relation between the $\omega\to\pi^0\gamma$ and $\rho\to\pi\gamma$ width is also in accord with Eq. (11) for the u/d -ratio and at the same time puts an upper limit on the pion exchange contribution to the isovector transitions between meson states. To improve reliability of the results extracted from data, we have chosen to compare only the transitions with the same particle either in an initial or in a final state and with approximately the same photon energy release In this way we have obtained the $\omega \to \eta\gamma$ and $\eta' \to \omega\gamma$ widths from those with ρ -meson and ratios of the overlap integrals $I^{q}_{\rho\eta(\eta')}$ and $I^{s}_{\varphi\eta}$ which characterize the nonstrange and strange quark content of η and η' - mesons. The ratios found from the radiative decays seem to be different from parameters of the same physical meaning which have been extracted from the $J/\psi \to VP$ -decays [32]. These are still not firmly established discrepancies due to existing large uncertainties. But, nevertheless, they deserve attention as the evidence for a more complex, multi-component composition of the η - and η' - mesons as well as the SU(3)-breaking in amplitudes of the $J/\psi \to V+P$ decays.

After this work was completed and going to press we aware of Ref.[38], where the relations, identical to our Eqs.(11) and (12), were derived for the quark magnetic moments and the role of the anomalous magnetic moments of quarks was also discussed in the radiative meson decays. Our parametrization for magnetic moments $\mu(B)$ of baryons ($B = P, N, \Sigma, \Xi$; $|B\rangle = |q_{like}\, q_{like}\, q_{unlike}\rangle$, $q = u, d, s$)

$$\mu(B) = \mu(q)_{like} \cdot g_2^B + \mu(q)_{unlike} \cdot g_1^B + C^B_{exch} \qquad (36)$$

consists in adopting $g_i^{P,N} = g_i^Y$, $Y = \Sigma, \Xi$; $C^{P,N}_{exch} \neq 0$ and $C^Y_{exch} = 0$ while that of Ref.[39] is reduced (in our notation) to $g_i^{P,N} \neq g_i^Y$, $C^B_{exch} = 0$, $g_1^B + g_2^B = 1$. The last assumption enables one to rewrite the parametrization of Ref.[39] for $\mu(P)$ and $\mu(N)$ in the form of Eq.(36) with $g_i^B = g_i^Y$ and $C^{P(N)}_{eff} = \pm(g_1^Y - g_1^{P,N})(u - d)$ from which the results (11) and (12) for u/d and s/d follow. Note also that combining the assumptions of this work with those of Ref.[39], namely, allowing the nonzero exchange current contributions to $\mu(P)$ and $\mu(N)$ ($C^{P,N}_{exch} \neq 0$) and keeping the SU(3)-relations only for the Σ and Ξ - hyperon wave functions ($g_i^{P,N} \neq g_i^Y$ but $g_1^B + g_2^B = 1$), leaves Eqs.(11) and (12) and sum rule (4) unchanged. Then (6) will define only the relation between $C^{P,N}_{exch}$ and the difference $g_i^{P,N} - g_i^Y$. The numerical values of Ref.[39] $g_1^Y \approx B' = -0.181$, $g_2^Y = 1 - B' = 1.181$, as well as $\mu(u) = 1.982$, $\mu(d) = -1.103$ and $\mu(s) = -0.753$ are also left unchanged. However, the empirical validity of the sum rules (3) and (14) can then be interpreted only as a result of unforeseen compensation in the corresponding relations of the SU(3)-breaking effects in the baryon wave functions.

References

1. Coleman S., Glashow S.L., Phys.Rev.Lett., 1961, 6, p.423.
2. Okubo S., Phys.Lett., 1953, 4, p.14.
3. Gürsey F., Radicati L., Phys.Rev.Lett., 1954, 13, p.173.
   Beg M.A.B., Lee B., Pais A., Phys.Rev.Lett., 1964, 13, p.514, 650 (E).
   Sakita B., Phys.Rev.Lett., 1964, 13, p.643.
4. Gerasimov S.B. ZhETP, 1966, 50, p.1559.
5. Rubinstein H. et al., Phys.Rev., 1967, 154, p.1608.
6. Lipkin H.J., Phys.Rev.Lett., 1978, 41, p.1629.
7. Jaffe R.L., in: Pointlike Structures Inside and Outside Hadrons, Proc. of the 1979 Erice Summer School, Ed. A.Zichichi, Plenum, N.Y. 1982.
8. Thomas A.W. Adv. Nucl.Phys., 1983, 13, p.1.
9. Sato T., Sawada S., Progr.Theor.Phys., 1981, 66, p.1713.
10. Theberge S., Thomas A.W., Nucl.Phys., 1983, A393, p.252.
11. Gaillard J.M., Sauvage G., Ann.Rev.Nucl.Part.Sci., 1984, 34, p.351.
12. Cheng T.P., Pagels H., Phys.Rev., 1968, 172, p.1635.
13. Lipkin H.J., Nucl.Phys., 1983, B241, p.477.
14. (a): Hertzog D.W., et al., Phys.Rev.Lett., 1983, 51, p.1131.
    (b): Wah Y.W., et al., Phys.Rev.Lett., 1985, 55, p.2551;
    (c): Zalapak G. et al., Phys.Rev.Lett., 1986, 57, p.1526.
15. Ankenbrandt C. et al., Phys.Rev.Lett., 1983, 51, p.863.
16. Wilkinson C. et al., Phys.Rev.Lett., 1987, 58, p.855.
17. Particle Data Group, Phys.Lett., 1986, 170B.
18. Franklin J. et al. Phys.Rev., 1981, D24, p.2910.
19. Donoghue J.F., Nappi C.R., Phys.Lett., 1986, 168B, p.105.
    Jaffe R.L., Korpa C.L., Preprint CTP-1443, 1987.
20. Okubo S., Phys.Rev., 1977, D16, p.2336.
21. Geffen D.A., Wilson W., Phys.Rev.Lett., 1980, 44, p.370.
22. Aznauryan I.G. et al. Yad.Fiz., 1980, 31, p.1680; ibid., 1984, 39, p.108.
23. Georgi H., Manohar A., Phys.Lett., 1983, 132B, p.183.
24. Mignani R., Prosperi D., Nuovo Cim., 1983, 75A, p.221.
25. Krivoruchenko M.I., Yad.Fiz. 1987, 45, p.169.
26. Petersen P.C. et al., Phys.Rev.Lett., 1986, 57, p.949.
27. Nefkens G. et al., Phys.Rev., 1978, D18, p.3911.
28. Gerasimov S.B., Yad.Fiz., 1979, 29, p.513.
29. Quigg C., Rosner J.L., Phys.Rep., 1979, C56, p.167.
30. Frank M., O'Donnell P.J., Phys.Rev., 1986, D32, p.1739.
31. Gerasimov S.B., Govorkov A.B. Z.Phys., 1987, C36, p.435.

32. Baltrusaitis R.M. et al., Phys.Rev., 1985, D32, p.2883.
33. Carlsmith D., et al., Phys.Rev.Lett., 1986, 56, p.18.
34. Druzhinin V.P. et al., Phys.Lett., 1984, 144B, p.136.
...t., 1987, B186, p.432.
36. Huston J., Phys.Rev., 1986, D33, p.3199.
37. Sachs R.G., Phys.Rev., 1981, D23, p.1148.
Brekke L., Sachs R.G., Phys.Rev., 1983, D28, p.1178.
38. Franklin J., Phys.Rev.Lett., 1980, 45, p.1607.
39. Brekke L., Rosner J.L. Preprint EFI 87-80, 1987.

Received by Publishing Department
on February 19, 1988.

Герасимов С.Б. E2-88-122

Магнитные моменты барионов и радиационные распады низших мезонных резонансов

Магнитные моменты октета барионов рассмотрены в рамках феноменологических правил сумм, включающих релятивистские эффекты и неаддитивные добавки, обусловленные обменными пионными токами. Полученные отношения магнитных моментов u, d, s-кварков ($\mu(u)/\mu(d) = -1{,}80$, $\mu(s)/\mu(d) = 0{,}68$) используются затем для анализа радиационных распадов векторных и псевдоскалярных мезонов. Параметры, характеризующие кварковый состав η- и η'-мезонов, сопоставляются с соответствующими величинами, полученными из рассмотрения адронных J/Ψ-распадов.

Работа выполнена в Лаборатории теоретической физики ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1988

Gerasimov S.B. E2-88-122

Magnetic Moments of Baryons and Radiative Decays of Lowest Meson Resonances

Magnetic moments of the octet baryons are considered in the framework of phenomenological sum rules based on the general groundwork of quark models that include relativistic effects and nonadditive corrections due to the pion exchange currents. The relations between the u,d,s-quark magnetic moments thus obtained are then used for an analysis of the vector and pseudoscalar meson radiative decays. The parameters related to the quark content of the η and η'-mesons are compared with the corresponding quantities extracted from the measured hadronic J/Ψ-decays.

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

Preprint of the Joint Institute for Nuclear Research. Dubna 1988