A.E.Dorokhov[1]

ELECTROMAGNETIC HADRON MASS DIFFERENCES AND ESTIMATION OF ISOTOPIC SYMMETRY VIOLATION PARAMETERS OF QCD VACUUM FROM QUARK MODEL

[1]E-mail: DOROKHOV@THSUN1.JINR.DUBNA.SU

1994

To describe the mass spectrum of hadronic ground states, it is actually necessary to define two quantities: the scale of hadronic masses and the scale of spin-spin splitting. Then the hadron spectrum is almost reproduced by using the $SU_f(3)$ symmetry. This is the reason for success of most models of hadrons. However, there exist more subtle effects such as, for example, electromagnetic mass differences (EMD) or the mass spectrum of excited and exotic states which as a whole are a good base to select the most adequate approach to the phenomenology of strong interaction at low energies.

At present, the possibility of determination of the isospin symmetry violation of light quark masses and their condensates is widely discussed within different approaches [1]-[7]. Mainly, the interest in this problem is based on the necessity to relate the isotopic symmetry violation on the level of hadrons to the differences of some intimate QCD parameters: masses and condensates of light quarks. This intriguing problem is well known for many years and is due to the absence of quantitative understanding of the QCD at low energies. During the past decade the data for hadron mass differences have become much more accurate [8]. For the joined treatment of the hadron masses and their isospin splittings based on QCD inspired approaches (QCD sum rules, Quark models) the important question is to determine, from the hadron spectrum, the magnitudes of isospin symmetry violation in the light quark masses and condensates.

Another point is that the isospin symmetry breaking effects are tightly related with charge symmetry breaking phenomena in nuclear physics. Understanding of the latter is very important for a more profound view on strong interaction forces [9].

On the one hand, EMD are just of electromagnetic nature (in the presence of strong interaction) and, in principle, calculable in terms of what is known. On the other hand, the effects that strong interaction creates can perhaps be avoided by using adequate approaches in calculations (e.g. Quark models, QCD sum rules, Lattice QCD). The mass differences between members of the same isospin multiplet are due to two reasons: the proper electromagnetic interaction between different quarks in a hadron, ΔE_{em}, and the self-interaction of the quarks themselves. The last one produces a difference between $u-$ and $d-$ quark masses, $\Delta m = m_d - m_u$, which results in the dependence of the strong interaction potential, ΔE_{strong}, and quark kinetic energy, ΔE_{kin}, on Δm.

A consistent consideration of the electromagnetic interaction of quarks
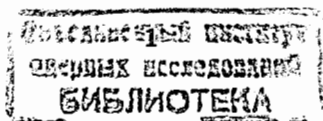
in the presence of strong interaction is possible within the relativistic bag model [10, 11]. It allows, in principle, to calculate the self-energy interaction and determine the $u-$ and $d-$ quark masses as the poles of the quark propagator in the bag. However, this problem is not fully solved yet [12]. So, we shall calculate the interactions between quarks with the value of the quark mass difference fixed by fitting to the experimental values of EMD.

In [13], in the framework of the MIT bag model [11], the electromagnetic interaction between different quarks in ground state hadrons, ΔE_{em}, has been calculated. It has been shown that EMD are much more sensitive to quark-quark wave function correlations than the masses and magnetic moments of hadron ground states and are a strong testing of the model. Further in [14], the dependence of the one-gluon exchange potential, ΔE_{gl}, on quark masses has been taken into account. The $u-d$ quark mass difference has been estimated, $\Delta m \approx 4~MeV$. It agrees with the current algebra estimation [15]. In [16], the effects of instantons and quark condensates on isomultiplet mass splitting of baryons has been considered. It has been shown that these contributions systematically improve the results for Σ and Ξ baryons. The important role of instantons for baryon octet splittings has been noted in [17], too.

In the present paper, we shall consider the isospin mass splittings of low - lying hadrons and obtain estimations of the isospin violation in quark masses and condensates. To this end, we shall use the version of the bag model based on the idea that the interaction of hadron constituents with background vacuum fields in the bag plays the dominant role [18] . It has been shown that the spin - dependent forces are determined by the interaction of quarks with instantons (short - range vacuum fluctuation) [18]-[20], while the stability (confinement forces) is due to their interaction with condensates (long - wave vacuum fluctuation) [18, 21]. This nonperturbative interaction between quarks strongly depending on quark masses defines the spectroscopy of the ground states of hadrons. The results obtained agree well with the experimental ones. In addition to the assumption made in [16], we shall take into account the center - of - masses and gluon condensate corrections to hadron masses and allow the $SU(2)$ violation of light quark condensates.

The main assumption of the model that the interaction of quarks and gluons localized in the bag (thus at effectively small distances) with background QCD vacuum fields defines the hadron structure is analogous to the QCD sum rule ideas [22, 23]. In the latter case the correlator of hadron currents is a nonlocal object selecting the lowest hadron states. Here, one also suggests implicitly that local sources do not perturb the properties of physical vacuum, i.e. the values of quark and gluon condensates. In our case the extended bag plays a role similar to a current correlator within the QCD sum rule.

Let us consider the total energy difference between two members of a multiplet. It is given by the expression:

$$\Delta M_{tot} = \left\{ \Delta E_{tot} - \frac{\Delta <P^2>}{2E_{tot}} \right\} \frac{E_{tot}}{M_{tot}} \qquad (1)$$

with

$$\Delta E_{tot} = \Delta E_{kin} + \Delta E_{em} + \Delta E_{strong}, \qquad (2)$$

and

$$\Delta E_{strong} = \Delta E_{vac} + \Delta E_{inst} + \Delta E_{gl},$$

where M_{tot} is a hadron mass, $M_{tot}^2 = E_{tot}^2 - <P^2>$, with center - of - mass motion correction $<P^2>$ taken into account [24], ΔE_{gl} is due to the QCD hyperfine interaction of quarks inside a bag, and ΔE_{vac} and ΔE_{inst} are due to the interaction of quarks with vacuum fields.

Detailed calculations of the contributions ΔE_{em}, ΔE_{kin} and ΔE_{gl} have been carried out in [13, 14]. These contributions for two members A and B of a multiplet are given by the expressions:

$$\Delta E_{kin} = \frac{1}{R} \sum_{i}^{u,d,s} (N_i^A - N_i^B)\omega(m_i R), \qquad (3)$$

$$\Delta E_{gl} = \frac{\alpha_s}{4R} \sum_{i>j}^{u,d,s} (N_{ij}^A - N_{ij}^B)M_{gl}^{ij} I_{gl}(m_i R, m_j R), \qquad (4)$$

$$\Delta E_{em} = \frac{\alpha}{R} \sum_{i>j}^{u,d,s} (N_{ij}^A - N_{ij}^B)M_{em}^{ij} I_{em}(m_i R, m_j R), \qquad (5)$$

where N_i is the number of light quarks of the flavour i in the hadron, N_{ij} is the number of light quark pairs in a hadron, m_i is the current quark mass, ω_i is the mode frequency, M^{ij} are averaged over the hadron state (color -) spin operator, I are strengths and α are couplings for gluon and

photon interactions, respectively. (Our definition of α_s differs from that used in [11] by factor 4 and corresponds to the standard definition used in QCD.)

It is important that in the framework of the bag model ΔE_{em} is calculated explicitly, with no free parameters. Contrary to the bag model, these values have been not determined within the QCD sum rules [3, 4] and so this method is not completely self - consistent in the determination of isotopic hadron mass differences.

The contributions, ΔE_{vac} and ΔE_{inst}, are discussed in detail in [18]. The first term is caused by the interaction of quarks with low - frequency vacuum fields which gives the confinement of quarks. The interaction Lagrangian is expressed by:

$$\Delta \mathcal{L}^{vac} = [\bar{q}(x)\Theta_V(x)](\frac{i}{2}\overset{\leftrightarrow}{\partial} - m)Q(x) + \bar{Q}(x)(\frac{i}{2}\overset{\leftrightarrow}{\partial} - m)[q(x)\Theta_V(x)] +$$

$$+ \quad g\bar{q}(x)\gamma^\mu \frac{\lambda^a}{2}q(x)\mathcal{A}^a_\mu(x)\Theta_V(x), \qquad (6)$$

Here the anticommuting external quark field Q and external gauge field $\mathcal{A}^a_\mu(x)$ are the vacuum solution of QCD equations parametrized by the values of their condensates, and the localized quark field $q(x)$ is given by the solution of the Dirac equation in a static spherical cavity of radius R; the function $\Theta_v(x)$ defines the volume V of the bag. Expression (6) follows directly from the QCD (bag) Lagrangian by singling a vacuum component out of the quark field: $\Psi(x) = q(x)\Theta_V(x) + Q(x)$ in analogy with the procedure used in the QCD sum rule technique [22]. It is supposed that these components weakly correlate with each other (see the discussion on hierarchy of vacuum and constituent fields in [18]c).

Vacuum condensate induced corrections to the hadron mass are calculated by using the stationary perturbation theory with the interaction Lagrangian (6). The resulting formulas are:

$$E^{QQ}_{vac} = -\left(\sum_i^{u,d,s} N_i A^{QQ}_i < 0|\bar{Q}_i Q_i|0 >\right) R^2 + ..., \qquad (7)$$

$$E^{GG}_{vac} = \left(\sum_i^{u,d,s} N_i A^{GG}_i\right) < 0|\frac{\alpha_s}{\pi}G^a_{\mu\nu}G^{a\mu\nu}|0 > R^3 + ..., \qquad (8)$$

with

$$A^{QQ}_i = \frac{\pi}{12}\frac{(\omega_i + m_i R)^2 \omega_i}{\xi_i^2 [2\omega_i(\omega_i - 1) + m_i R]}, \qquad A^{GG}_i = \frac{\pi^2}{144}I^{GG}(m_i R),$$

where $< 0|\bar{Q}_i Q_i|0 >$ is the quark condensate of the i-th flavour, $< 0|\frac{\alpha}{\pi}G^a_{\mu\nu}G^{a\mu\nu}|0 >$ is the gluon condensate, $\omega_i = (\xi_i^2 + m_i^2 R^2)^{1/2}$ is the one - particle frequency, and ξ_i is determined from the solution of the equation originating from the bag boundary condition:

$$\tan \xi_i = \xi_i/[1 - m_i R - (\xi_i^2 + m_i^2 R^2)^{1/2}], \qquad (9)$$

$I^{GG}(m_i R)$ is a function of masses with, for instance, $I^{GG}(0) = 0.124$ and $I^{GG}(m_s R = 1.1) = 0.130$. The calculations of E^{QQ} and E^{GG} are carried out in a fixed - point gauge [23]. Dots in (7) and (8) mean the contributions of condensates of higher dimensions which are numerically suppressed [18].

From (7) in the first order of expansion in the small quark mass parameter m_q and the difference $\gamma = \frac{<\bar{D}D> - <\bar{U}U>}{<\bar{U}U>}$, $(\gamma < 0)$, we obtain an increase of the hadron mass by:

$$\Delta E_{vac} = \quad - <\bar{U}U> R^2 \{B^{QQ} \sum_{i=u,d} N_i m_i + \frac{\pi}{24(\xi_0 - 1)}N_d \gamma\}$$

$$+ <\frac{\alpha_s}{\pi}G^2> R^3 B^{GG} \sum_{i=u,d} N_i m_i, \qquad (10)$$

where $B^{QQ} = \left(\frac{\partial A^{QQ}}{\partial m_q}\right)_{m_q = 0} \approx 0.202\ GeV^{-1}$ and

$B^{GG} = \left(\frac{\partial A^{GG}}{\partial m_q}\right)_{m_q = 0} \approx 0.0098\ GeV^{-1}$.

Many - particle interactions have in principle a small - distance character and may be approximated by the effective t'Hooft interaction [25] induced by the high - frequency part of gluon field vacuum fluctuations, small-size instantons. In the instanton vacuum model [26, 27] it is expressed by [18]:

$$\Delta \mathcal{L}^{(2)}_{inst} = \sum_{i>j}^{i=u,d,s} n_c(k'_i k'_j)\{\bar{q}_{iR}q_{iL}\bar{q}_{jR}q_{jL}[1 + \frac{3}{32}\lambda^a_i \cdot \lambda^a_j(1 + 3\vec{\sigma}\cdot\vec{\sigma})] + (R \leftrightarrow L)\}$$

$$(11)$$

where the coupling

$$k'_i = \frac{4\pi \rho_C^3}{3} \frac{\pi}{(m_i^* \rho_C)} \tag{12}$$

characterizes the interaction strength of a quark of flavor i with an instanton and is proportional to the instanton volume, n_c is the instanton density in the QCD vacuum related to the vacuum energy density, ε_{QCD}, by $\varepsilon_{QCD} = 2n_c$, $n_c = \frac{1}{16} < 0|\frac{\alpha}{\pi} G_{\mu\nu}^a G^{a\mu\nu}|0 >$, ρ_c is an effective size of an instanton in the QCD vacuum, $q_{R,L} = \frac{1}{2}(1 \pm \gamma_5)q$, $m_i^* = m_i - \frac{2}{3}\pi^2 \rho_c^2 < 0 | \bar{Q}_i Q_i | 0 >$ is the effective mass of the quark with current mass m_i in physical vacuum [26]. An effective mass takes into account long-range field correlations in the instanton vacuum. The term $(R \leftrightarrow L)$ in (11) corresponds to the interaction through an anti-instanton. The Lagrangian (11) is written for qq-interaction in the $SU_f(2)$ flavor sectors of the complete $SU_f(3)$ theory. Selection of $SU_f(2)$ corresponds to the case when two of quarks are exchanged by a hard instanton fluctuation and a quark of the third flavour interacts with soft vacuum condensate. For the $q\bar{q}$ - system one should change in (11) operators of one of quarks

$$\lambda_q^a \to -\lambda_q^{aT}, \quad \vec{\sigma}q \to -\vec{\sigma}_q^T.$$

In the recent paper [28] D. Klabucar analyzes the octet baryon mass spectrum in the framework of the MIT bag model with instanton induced interaction. He finds that the instanton contributions to hadron masses are less than 5 MeV and, therefore, completely negligible. This conclusion is in strong contradiction with the results of works [18, 20] and can be traced to illegal inclusion of the one - particle part, $\Delta L_{inst}^{(1)} \propto \bar{q}_i q_i$, of the instanton interaction into the calculation of hadron masses. This potentially large contribution is suppressed then by choosing a very small value of the package factor f, $f = \pi^2 n_c \rho^4$ (one thirtieth of a standard value [27]). Then the contribution of $\Delta L_{inst}^{(1)}$ is at the level of several MeV and that of $\Delta L_{inst}^{(2)}$ is even much less. However, the inclusion of $\Delta L_{inst}^{(1)}$ being correct in the case of a quark in the background vacuum field [26] is to be double counting procedure within the bag model. As it is truly noted in [28] within the nonrelativistic quark model [20] the one - particle term $\Delta L_{inst}^{(1)}$ is effectively taken into account as a part of a constituent quark mass and thus it does not appears explicitly. But the same occurs within the relativistic bag model where the constituent mass

results from the bag boundary conditions: $m_q \to m_q^{const} = \sqrt{m_q^2 + \xi^2 R^2}$. The bag boundary conditions take already into account quark dressing by the vacuum "medium". That is why in [28] there is no more place for instantons and that is why we do not include the one - particle term into our considerations.

In the first order in small u, d quark masses and condensate difference we obtain from (11) the hadron energy increase resulting from instantons

$$\Delta E_{inst} = -\frac{E_{inst}^{(os)}(h)}{m_0^*}\{ \sum_{i=u,d} N_{is}m_i - \frac{2\pi^2}{3}\gamma N_{ds} < 0|\bar{U}U|0 > \rho_c^2\}, \tag{13}$$

where N_{is} is the number of light - strange scalar diquarks in a hadron, h, m_0^* is an effective mass of a quark with a zero current mass and $E_{inst}^{os}(h)$ is the instanton correction for these diquarks calculated with the static spherical cavity wave functions

$$E_{inst}^{os}(h) = - < h|\Delta L_{inst}^{os}|h > . \tag{14}$$

The values of $E_{inst}^{os}(h)$ for members of hadron multiplets are the following:

$$E_{inst}^{os}(\pi) = 0, \quad E_{inst}^{os}(K) = -\frac{\lambda_{0s}^0}{R^3}, \tag{15}$$

$$E_{inst}^{os}(N) = 0, \quad E_{inst}^{os}(\Sigma) = E_{inst}^{os}(\Xi) = -\frac{1}{2R^3}\left(\frac{3}{2}\lambda_{0s}^0 + \frac{1}{2}\lambda_{0s}^1\right),$$

where $\lambda_{i,j}^l = n_c k'_i k'_j I_{i,j}^l$ with l for spin of a diquark and integrals are

$$I_{i,j}^0 = \frac{3}{4\pi}N_i^2 N_j^2 \int_0^1 dx \, x^2 \left[\sqrt{1 + \frac{m_iR}{\omega_i}}\sqrt{1 + \frac{m_jR}{\omega_j}}j_0(\xi_i x)j_0(\xi_j x) + \right.$$
$$\left. + \sqrt{1 - \frac{m_iR}{\omega_i}}\sqrt{1 - \frac{m_jR}{\omega_j}}j_1(\xi_i x)j_1(\xi_j x) \right]^2 ,$$

$$I_{i,j}^1 = -\frac{1}{4\pi}N_i^2 N_j^2 \int_0^1 dx \, x^2 \left[\sqrt{1 + \frac{m_iR}{\omega_i}}\sqrt{1 - \frac{m_jR}{\omega_j}}j_0(\xi_i x)j_1(\xi_j x) - \right.$$
$$\left. - \sqrt{1 - \frac{m_iR}{\omega_i}}\sqrt{1 + \frac{m_jR}{\omega_j}}j_1(\xi_i x)j_0(\xi_j x) \right]^2 ,$$

N_i is the normalization of the wave function of a quark with mass m_i:

$$N_i^{-2} = j_0^2(\xi_i)[2\omega_i(\omega_i - 1) + m_i R]/\omega_i(\omega_i - m_i R).$$

ξ_i is a root of the equation (9). We should note that the contribution to a vector diquark results from the inequality of quark masses and is very small as compared to the scalar diquark integral even on the scale of a strange quark mass.

Due to the determinant character of instanton induced quark interaction (11), for members of the meson vector nonet and baryon decouplet the corrections (14) are equal to zero. This selection rule comes from the fact that the instanton mechanism of interaction within a hadron takes place only if two quarks are in the state with zero total spin (plus color spin), the scalar diquark.

The results of calculations are presented in Table I. The numbers in Table I correspond to the parameters of the QCD vacuum:

$$< 0|\bar{U}U|0 > = -(221 \ MeV)^3,$$
$$< 0|\frac{\alpha_s}{\pi}G^2|0 > = 0.031 \ GeV^4, \qquad \rho_c^2 = 1 \ GeV^{-2}, \qquad (16)$$

the differences of u and d quark masses ($m_u = 5 \ MeV$)

$$m_d - m_u = 3.5 \ \text{MeV}, \qquad (17)$$

and their condensates

$$\gamma = \frac{<\bar{D}D> - <\bar{U}U>}{<\bar{U}U>} = -2 \cdot 10^{-3}. \qquad (18)$$

In our calculations we take the values $m_s = 200 \ MeV$, $\alpha_S = 0.4$ and $\delta = \frac{<\bar{S}S> - <\bar{U}U>}{<\bar{U}U>} = -0.1$. We should note that the reduction of Δm_q, as compared with [14], is due to the center - of - mass motion effects (1).

We use the value of the quark condensate which agrees with the standard one [23]: $< 0|\bar{U}U|0 > = -(225 \pm 25 \ MeV)^3$. The value of the gluon condensate is close to a recent estimation extracted from the two loop fit of charmonium data [31]: $< 0|\frac{\alpha_s}{\pi}G^2|0 > = 0.021 \ GeV^4$ which is almost twice as the standard one [23]. The interaction with the condensates resemble the one - particle contribution to a quark mass due to long-range

fluctuations of vacuum medium and for the proton state this increase is approximately equal to $\Delta m_q^{vac} \approx 270 \ MeV$. On the other hand, the value of the instanton quark-quark interaction strength is sensitive to the ratio of quark and gluon condensates, (11), (12), and provides a large negative contribution to the proton energy, $\Delta E_{inst}^{00} \approx -210 \ MeV$.

The value of ρ_c^2 that we use in this paper is slightly less than obtained in the instanton liquid model [27, 29]. It leads to a lower value of an effective (chiral) mass parameter $m_0^* \approx 70 \ MeV$. This causes two effects: large instanton contributions to the EMD of baryon the octet due to the $1/m_0^*$ dependence of these differences and a more stronger suppression of instanton interaction in the light - strange diquark: $m_0^*/m_s^* \approx 0.3$ as compared with $m_0^*/m_s^* \approx 0.6$ in [27]. Small values of ρ_c^2 and m_0^* are characteristic of the chiral phase in the framework of the confining QCD vacuum model developed in [32].

Another important vacuum parameter is a packing fraction characterizing the diluteness of instanton vacuum. With our choice of parameters it is quite small:

$$f = (2n_c)\frac{\pi^2 \rho_c^4}{2} \approx 1/50 \qquad (19)$$

and justifies the one - instanton approximation used. The value of f that we use corresponds exactly to the one obtained in the Monte Carlo lattice calculations [33].

We now turn to the discussion of EMD. There are two exceptional EMD combinations which depend only on the electromagnetic term ΔE_{em} thus being sensitive only to the bag radius. They are the $I = 2$ part of the $\Sigma-$ and the π mass differences: $\Sigma^+ + \Sigma^- - 2\Sigma^0 = 1.71 \pm 0.15 \ MeV$, $\pi^\pm - \pi^0 = 4.59 \pm 0.05 \ MeV$ (this is valid for $\rho^\pm - \rho^0$, too, but its experimental value is not well defined). The first one is satisfied in the range of bag radii $R = 5 \sim 6 \ GeV^{-1}$, which confirms a good and self - consistent description of the mass scales of the baryon octet and splittings within it. From Table I we see that the bag stability radius, $R = 5.6 \ GeV^{-1}$, belongs to this interval and $\Sigma^+ + \Sigma^- - 2\Sigma^0 = 1.71 \ MeV$ in fine agreement with experimental value. As to the pion, due to large negative instanton and c.m. energy contributions, it has no radius of bag stability. This is a signal of the Goldstone nature of the pion in our model. As it has previously been pointed out [18], the effects of relativism and multiparticle structure of the pion wave function are urgently necessary to describe the pion within the bag model.

Given a typical bag radius and due to the absence of instanton contribution, the $p-n$ mass difference ($p-n = 1.3\ MeV$) is mainly defined by the sum of the electromagnetic energy term, ΔE_{em}, and the kinetic energy term, ΔE_{kin}. The latter directly depends on the $u-d$ quark mass difference. We could obtain the experimental value precisely by fitting Δm_q with an accuracy of $0.01\ MeV$. However, we think that the calculations with such a high accuracy can not be made within the bag model approach. Within some uncertainties in the definition of the model parameters, the value of Δm_q is grouped around $3.5\ MeV$.

Usually, in the bag model there is the problem with the description of the $I = 1$ part of octet splitting. In fact, the bag radius and Δm_q fixed as above, it is impossible to saturate the Coleman - Glashow relation (CG), $p-n + \Xi^0 - \Xi^- = \Sigma^+ - \Sigma^-$, only with the kinetic energy, ΔE_{kin}, and electromagnetic energy, ΔE_{em}, contributions. That is, $CG_0^{theor} = \Delta E_{kin}^{CG} + \Delta E_{em}^{CG} + ... \approx -4.5\ MeV$ while the experimental value is about $CG^{ex} \approx -8\ MeV$. It is important to stress that the color - magnetic energy contribution could not save the situation with CG even for the large constant $\alpha_s^{MIT} = 2.2$.

As it has been noted in [16, 17] the $I = 1$ part of the $\Sigma-$ and $\Xi-$ mass differences is essentially due to the instanton contribution that is proportional to the number of strange quarks. It reproduces the term introduced phenomenologically in [13]. It is important that these splittings are of the same order as the $u-$, $d-$ quark mass differences. Then from (13) one has: $\Delta E_{inst}^\Sigma = \frac{E_{inst}^{0s}}{m_0^*}\Delta m_q$, and for typical values for $E_{inst}^\Sigma \approx -70\ MeV$ it follows that the effective quark mass m_0^* is of the same order as E_{inst}^Σ. This ratio requires quite a small value for $m_0^* \sim <\bar{Q}Q> \rho_c^2$ and a large value for a gluon condensate $E_{inst} \sim <0|\frac{\alpha_s}{\pi}G^2|0> / <\bar{Q}Q>^2$, (16). The Coleman - Glashow relation is satisfied by each contribution separately because, as noted above, the bag radii for N, Σ, Ξ are well equal. As to the absolute value of the left and right sides of this relation, the instanton contribution is very important. From Table I we find $p - n + \Xi^0 - \Xi^- = -8.30\ MeV$ $(-7.7 \pm 0.6\ MeV)_{exp}$ and $\Sigma^+ - \Sigma^- = -8.06\ MeV$ $(-8.07 \pm 0.09\ MeV)$ in excellent agreement with experiment values.

Thus, it is shown that the instanton plays the key role in the saturation of the CG relation between octet baryon states. In this case, as in the case of the dynamical explanation of the Okubo - Zweig - Iizuka rule [34], the gluon exchange contributions are very small and, therefore, from the magnitudes of these effects we can clearly judge on the strength of the instanton induced interaction.

The contributions related to the condensate difference are not large, act opposite to the first terms in (10), (13) and are poor fixed from hadron mass differences. From our analysis we can define only the lower bound of γ: $0 > \gamma > -0.003$. With a precision of the model and data it is difficult to expect for more.

We have compared the results using linear and quadratic bag model formulae. As a rule, the center - of - mass corrections lead to larger bag radii, additional corrections to ΔE_{kin} which partially contribute to the CG relation. The main effect of the center of mass motion corrections on parameters reduce Δm_q approximately by $0.5\ MeV$.

From Table I we see that the interaction induced by instantons gives an essential contribution to the isotopic mass differences of hadrons belonging to a baryon octet and pseudoscalar mesons. As expected, the quantitative agreement with experimental values for the pseudoscalar octet is not entirely satisfactory. As noted above, in the problem of the masses and their splittings of the pseudoscalar octet it is necessary to take into account the higher orders in the instanton interaction. Another problem is the difference of vector strange mesons $K^{*+} - K^{*0}$. This discrepancy between the theoretical prediction and the values from Particle Data looks strange because we do not see any large contribution to this difference. We hope that more precise experiments on determining the electromagnetic differences of vector resonances will clear up the situation.

At last, we would like to say a few words about other approaches. In [2, 3, 6], the problem concerned has been discussed within the QCD sum rule method. There, the important contribution of the interaction with small-size instantons that dominates in the short wavelength region of vacuum fluctuations has been missed. However, in our opinion, this interaction is of principal importance. It violates the quark additivity, specifies spin-spin splitting in the hadron mass spectrum and determines the mixing angles in the hadron $SU(3)_f$ multiplets. In [30, 35], it has been shown that the consideration of the QCD sum rules for the pion and proton confirms the fundamental role of instanton interaction on which the model is based. This conclusion is also proved in Lattice QCD calculations [36]. Another problem of the QCD sum rules method is to take into account the $\Sigma^0 - \Lambda$ mixing [3], the effect of which is negligible within the quark model [37].

Particles	R	M	ΔM_{kin}	ΔM_{EM}	ΔM_{gl}	ΔM_{vac}	ΔM_{inst}	ΔM_{tot}	ΔM_{exp}
P-n	5.60	940	-1.06	0.55	0.04	-0.15	0	-1.23	-1.2933± 0.002
$\Sigma^+ - \Sigma^0$	5.40	1230	-1.19	0.55	-0.01	-0.13	-1.49	-3.18	-3.18 ±0.17
$\Sigma^0 - \Sigma^-$			-1.19	-1.16	-0.01	-0.13	-1.49	-4.89	-4.89 ±0.08
$\Xi^0 - \Xi^-$	5.30	1330	-1.22	-1.21	-0.07	-0.13	-3.16	-7.07	-6.4 ±0.6
$\Delta^{++} - \Delta^0$	6.40	1240	-2.56	2.51	0.08	-0.48		-1.75	-2.70 ±0.30
$\Delta^+ - \Delta^0$			-1.28	0.48	0.04	-0.24	0	-1.61	
$\Delta^0 - \Delta^-$			-1.28	-0.97	0.04	-0.24	0	-2.90	
$\Sigma^{*+} - \Sigma^{*-}$	6.65	1380	-2.66	-0.50	0.08	-0.56	0	-4.89	-4.4 ±0.5
$\Sigma^{*0} - \Sigma^{*-}$			-1.33	-0.94	0.04	-0.28	0	-3.03	-3.5 ±1.2
$\Xi^{*0} - \Xi^{*-}$	6.70	1510	-1.37	-0.96	0.03	-0.29	0	-3.18	-3.2 ±0.6
$K^+ - K^0$	5.70	700	-0.87	0.56	-0.11	-0.16	-3.34	-5.40	-4.024 ±0.032
$\rho^\pm - \rho^0$	6.00	780	0.00	0.77	0	0	0	0.75	-0.3 ±2.2
$K^{*+} - K^{*0}$	6.00	890	-1.07	0.53	0.03	-0.20	0	-1.19	-6.7 ±1.2

In summary, we conclude from our results for isospin mass hadron differences that $m_d - m_u = 3.5 MeV$ and $< \bar{D}D > - < \bar{U}U > = -(0 \sim 3) \cdot 10^{-3} < \bar{U}U >$. It would be interesting to consider the D and D^* isospin mass differences in the framework of the quark model with QCD vacuum induced interaction.

References

[1] T. Hatsuda, H. Hogaasen, M. Prakash, *Phys. Rev.* **C42** (1990) 2212; *Phys. Rev. Lett.* **66** (1991) 2851;

[2] C. Adami, G.E. Brown *Z. Phys.***A340** (1991) 93.

[3] G. Adami, E. Drukarev, B.L. Ioffe *Phys. Rev.* **D48** (1993) 2304.

[4] V.L. Eletsky, B.L. Ioffe *Phys. Rev.* **D48** (1993) 1587.

[5] E. Gabrielli, P. Nason *CERN preprint* CERN-TH.6857/93 (1993).

[6] K.-C. Yang, W.-Y.P. Hwang, E.M. Henley, and L.S. Kisslinger *Phys. Rev.* **D48** 3001 (1993).

[7] X. Jin, M. Nielsen, J. Pasupathy *preprint* DOE/ER/40762-027; UMPP 94-082 (1994).

[8] Review of Particle Properties *Phys. Rev.* **D45** (1992) 1.

[9] G.A. Miller, B.M.K. Nefkens, I. Slaus *Phys. Rep.* **194** (1990) 1.

[10] P. N. Bogoliubov *Ann. Inst. H. Poincare* **8** (1967) 163.

[11] A. Chodos, R. L. Jaffe, K. Johnson, and C. B. Thorn *Phys. Rev.* **D10** (1974) 2599.

[12] G.V. Schreiber, R.D. Viollier *Ann. of Phys.* **215** 277 (1992) and references therein.

[13] N.G.Deshpande et.al *Phys. Rev.* **D15** (1977) 1885; L.P.Singh *Phys. Rev.* **D22** (1980) 2224.

[14] R.P. Bickershtaff, A.W. Thomas *Phys. Rev.* **D25** (1982) 1869.

[15] See for a recent review, H. Leutwyller *Bern University preprint* **BUTP-94/8** (1994).

[16] A. E. Dorokhov, N. I. Kochelev *Z. Phys.* **C37** (1988) 377.

[17] G. Yang, L. Wang, H.C. Liu *Z. Phys.* **C26** (1984) 77.

[18] A. E. Dorokhov, N. I. Kochelev *Sov. J. Nucl. Phys.* **52** (1990) 135 (214);
In Proc. Int. Conf. *Quarks-86, Tbilisi*, p. 392, Moscow, 1986;
A. E. Dorokhov, N. I. Kochelev, Yu. A. Zubov *Sov. J. Part. Nucl. Phys.* **23** (1992) 522 (1192).

[19] N. I. Kochelev *Sov. J. Nucl. Phys.* **41** (1985) 291.

[20] E. V. Shuryak, J. Rosner *Phys. Lett.* **218B** (1989) 72.

[21] T. H. Hansson *Nucl. Phys.* **B249** (1986) 742.

[22] M.A.Shifman, A.I.Vainstein, V.I.Zakharov *Nucl. Phys.* **B147** (1979) 385.

[23] For a review, see L.J. Reinders, H. Rubinustein, S. Yazaki *Phys. Rep.* **127** (1985) 1.

[24] J. Donoghue, K. Johnson, *Phys. Rev.* **D21** (1980) 1975.

[25] 't Hooft *Phys. Rev.* **D14** (1976) 3432; *Phys. Reports* **142** (1986) 357.

[26] M.A.Shifman, A.I.Vainstein, V.I.Zakharov *Nucl. Phys.* **B163** (1980) 45.

[27] E. V. Shuryak, *Phys. Reports* **115** (1984) 151.

[28] D. Klabucar *Phys. Rev.* **D49** (1994) 1506.

[29] D.I. Dyakonov, V.Yu. Petrov *Nucl. Phys.* **B272** (1986) 457.

[30] E. V. Shuryak, *Nucl. Phys.* **B214** (1983) 237.

[31] D.J. Broadhurst et. al. Preprint OUT-4102-49, March, 1994.

[32] Yu.A. Simonov ITEP preprint **83-93** Moscow, 1993.

[33] M. Campostrini, A. Di Giacomo, G. Mussardo *Z.Phys.* **C25** (1984) 173.

[34] B.V. Geshkenbein, B.L. Ioffe *Nucl. Phys.* **B166** (1980) 340.

[35] A.E.Dorokhov, N.I.Kochelev *Z.Phys.* **C46** (1990) 281.

[36] E. V. Shuryak, *Rev. Mod. Phys.* **65** (1993) 1.

[37] J. Franklin et. al. *Phys. Rev.* **D24** (1981) 2910.