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On the Delta-Nucleon and Rho - Pi Splittings:
A QCD-inspired Look in Free Hadrons versus Nuclei

Nimai C. Mukhopadhyay[(a,b)] and Vicente Vento[(a)]

(a) Departament de Fisica Teòrica and Instituto de Física Corpuscular
Universitat de València - Consejo Superior de Investigaciones Científicas
46100 Burjassot (València), Spain
(b) Department of Physics, Applied Physics and Astronomy
Rensselaer Polytechnic Institute
Troy, NY 12180-3590, USA

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ABSTRACT

Relationships between mass intervals for free hadrons and in nuclei are studied in two theoretical approaches inspired by QCD: naive quark model and skyrmion model, taking one example each from mesons and baryons, that of pi-rho splitting in mesons, and nucleon-Delta splitting in baryons. Possible deconfinement effects in nuclei are examined.

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`nimai@nimai.phys.rpi.edu`
`vicente.vento@uv.es`

1 Introduction

Given the success of the standard model (SM) of the strong and electroweak interactions, all ingredients of understanding hadron properties are in place at least through the energy scales set by the masses of the W and Z bosons. The detailed structure studies of hadrons form a new frontier of nuclear physics.

One aspect of this frontier is the study of *known* nuclear phenomena in terms of the degrees of freedom of QCD, viz., quarks and gluons. In the non-perturbative domain of QCD, the most rigorous attempts to compare the properties of hadrons use lattice methods. There are, however, numerous models inspired by QCD to do the same in various approximations. Two examples of the latter, to be used in this paper, are the quark model [1, 2] and the skyrmion model [3, 4].

An important inference from QCD is that the complex nucleus forms a new vacuum, wherein new strong interaction phenomena are expected to occur [5]. While traditional nuclear methods may work extremely well at low energy, low temperature and/or nuclear density, QCD provides new insights into novel nuclear phenomena, many of which cannot be described by the traditional nuclear many-body techniques. For example, formation of quark-gluon plasma is anticipated in QCD, and is beyond the domain of traditional nuclear physics.

The purpose of this paper is to examine the splitting of the baryons and mesons in free hadrons and in complex nuclei in two QCD-inspired models, quark model and skyrmion model, taking the mass intervals

$$\begin{aligned} \Delta(1232) \quad &- \quad N, \\ \rho(770) \quad &- \quad \pi, \end{aligned} \tag{1}$$

N being the nucleon and the π the pi meson. In (1), we shall ignore the isospin breaking. For free baryons, the above interval will be called ΔM, and in nuclei ΔM^*; similarly Δm and Δm^* for mesons respectively.

Reasons for taking these particular intervals are partly theoretical and partly experimental. In the baryon case, there have been extensive studies of the production and decay of $\Delta(1232)$, both off nucleons and in nuclei, in the pi-meson factories [6] and also by photons [7]. On the face of it, the intervals ΔM and ΔM^* seem to be not very hard to infer, ΔM being directly known, and the properties of $\Delta(1232)$ and nucleon in nuclei can be used as inputs to determine ΔM^*. Attempts to study higher energy baryon resonances in nuclei have resulted in the discovery that many of these resonances essentially disappear in nuclei heavier than the deuteron. Thus, quantitative information on them are difficult to obtain.

The mesonic interval Δm^* is not as well-known experimentally in nuclei. Interpretation of Δm and Δm^* is also difficult, given the complex property of the pion as a Goldstone boson. Nevertheless, a discussion of the $\rho - \pi$ interval is theoretically very interesting. In the naive quark model, it is simply related to the $\Delta - N$ interval via the color hyperfine interaction [2]. Thus, we shall consider it in this paper, speculating about its value in nuclei.

We note, at the outset, that traditional nuclear many-body methods (e.g. [8]) can be used, with a great deal of success, to discuss theoretically these intervals in nuclei. Thus, for ΔM^*, particle-hole and Delta-hole methods ([8]-[10]) are very successful in explaining this interval in terms of complex nuclear dynamics, *without invoking* QCD. Indeed, we cannot hope to even approach such successes in the QCD-based approaches at present. However, our modest goal is to offer different insights and connections in a subject well-known in the traditional nuclear physics domain; we believe that these are not easily gotten in the latter. Thus, the intrinsic connection between the baryonic and mesonic intervals, due to quark-gluon structure, is impossible to obtain in the traditional many-body approaches not based on QCD, and we want to profit from the former here.

2 The Quark Model Approach

2.1 Free hadrons

In the nonrelativistic quark model, the vector (V)- pseudoscalar(PS) meson splitting is determined in terms of the color magnetic hyperfine interaction [2]. Let us recall the model of ref. [11] for the ground-state hadron masses. The relevant meson masses for determining the mesonic interval are given by

$$m(\pi) \approx 2m_u - \frac{3a}{m_u^2}, \tag{2}$$

$$m(\rho) \approx 2m_u + \frac{a}{m_u^2}, \tag{3}$$

where a is the hyperfine constant defined by

$$a = \frac{8\pi}{9}\alpha_S |\Psi(0)|^2, \tag{4}$$

α_S is the strong fine-structure constant and we are using, for the up and down constituent quark masses, the approximation $m_u = m_d$, the quark density at the origin, $\Psi(0)$, being not very model-dependent. From Eqs. (2) and (3) one obtains for the mesonic interval

$$\Delta m \approx \frac{4a}{m_u^2}. \tag{5}$$

Analogously in the baryon case [2],

$$M(N) \approx 3m - \frac{a'}{m_u^2}, \tag{6}$$

$$M(\Delta) \approx 3m_u + \frac{a'}{m_u^2}, \tag{7}$$

where a' is the hyperfine constant for defined by

$$a' = \frac{2\pi}{3}\alpha_S|\Psi(0)|^2, \tag{8}$$

leading to

$$\Delta M \approx \frac{2a'}{m_u^2}. \tag{9}$$

Choosing $a \approx a'$ we obtain

$$\Delta M \approx \frac{2a}{m_u^2} \approx \frac{1}{2}\Delta m \approx 300 \text{ MeV}, \tag{10}$$

which is well-satisfied by the data. This well-known result is a reflection of the rôle of the color dynamics in the masses of hadrons[2, 11].

2.2 Hadrons in nuclei

We assume that the constituent quark mass and the hyperfine constant *both* change due to altered QCD vacuum in the nuclear medium [5]. Let M_u and A denote respectively the in-medium values of these parameters, which are related to the free values by

$$M_u = m_u + \delta, \tag{11}$$

$$A = a + \varepsilon. \tag{12}$$

We have, for nuclei,

$$m^*(\pi) \approx 2M_u - \frac{3A}{M_u^2}, \tag{13}$$

$$m^*(\rho) \approx 2M_u + \frac{A}{M_u^2}, \tag{14}$$

$$M^*(N) \approx 3M_u - \frac{A}{M_u^2}, \tag{15}$$

$$M^*(\Delta) \approx 3M_u + \frac{A}{M_u^2}, \tag{16}$$

2.3 Analysis of quark model parameters for nucleon and Delta

The experimental situation in complex nuclei can be summarized by the following [6, 7]:

$$M^*(\Delta) \approx M(\Delta) \approx 1232 \pm 35\text{MeV}, \tag{17}$$

$$M^*(N) < M(N) \tag{18}$$

We shall take the effective mass of the nucleon in nuclei to be

$$M^*(N) \approx 0.7M(N), \tag{19}$$

even as a bigger reduction of effective mass is indicated in the Dirac-Brueckner-Hartree-Fock theories [12]. Thus we shall take

$$M^*(\Delta) - M^*(N) \approx 576 \text{ MeV}. \tag{20}$$

From Eqs. (6) and (7),

$$m_u \approx \frac{M(\Delta) + M(N)}{6} \approx 362 \text{ MeV}. \tag{21}$$

From Eqs. (11), (12), (15), (16) and (20), we obtain

$$\delta \approx -47 \text{ MeV}, \tag{22}$$

therefore $|\delta| << m_u$. Using this result and Eq. (10) we get

$$\frac{2A}{M_u^2} \approx \frac{2\varepsilon}{m_u^2} + \Delta M \left(1 - \frac{2\delta}{m_u}\right) \approx M(\Delta) - 0.7M(N). \tag{23}$$

Thus

$$\frac{\varepsilon}{m_u^2} = 97 \text{ MeV}. \tag{24}$$

A comparison of Eq. (10) and (24) indicates that a and ε are comparable in magnitude given Eqs. (17) and (19).

We can summarize our effective baryon analysis in comparing free and nuclear properties: the effective quark mass in the nuclear medium becomes

$$M_u = m_u + \delta \approx 315 \text{ MeV}, \tag{25}$$

smaller than the free quark mass of 362 MeV (Eq. (21)). This drop in the quark mass is in accord with the studies[12] in the Nambu-Jona Lasinio [13] model, where a sharp drop of the quark mass is expected as a function of the nuclear Fermi momentum. The hyperfine interaction term for the free baryons

$$\frac{a}{m_u^2} \approx \frac{M(\Delta) - M(N)}{2} \approx 147 \text{ MeV}, \tag{26}$$

is less than

$$\frac{A}{m_u^2} \approx 287 \text{ MeV}, \tag{27}$$

indicating that $A > a$. This is suggestive of an increase of the effective coupling constant, α_S^{eff}, in the nuclear medium and could be an indication of an interesting QCD effect in the properties of baryons in the medium, that of hadronic deconfinement. The phenomenon could be investigated from the properties of baryonic resonances in the nuclear medium, thus opening a complementary line of research to that at the high energy scale, i.e.,EMC type studies [14], where similar phenomena have been observed. How our non-perturbative deconfinement scenario is related to the *nucleon swelling* discussion is still under scrutiny.

There are obviously many important implications of the phenomenon in nuclei we have discussed above resulting in $M_u < m_u$ and $A > a$. These involve various spectroscopic properties of baryons (and mesons) in nuclei, some of which we shall discuss in a later section.

2.4 Analysis of quark model parameters for pi and rho

Requirement of self-consistency of the quark model demands that the parameters obtained from the baryons and the mesons should broadly agree with each other. This is generally the case, though the agreement is not always perfect. An analysis of *all* mesons and baryons yield such an agreement overall [15]. As we know, the cases for the Goldstone bosons are always special and some disagreements involving them are not surprising [16]. We shall examine below this issue.

If we compute the quark mass from the vector mesons [11], the value for the mass is 390 MeV, quite close to the determination from baryons. However, from the formulas for the free pions and rhos, Eq. (2) and (3) one obtains [11]

$$m_u \approx \frac{m(\pi) + 3m(\rho)}{8} \approx 306 \text{ MeV} \tag{28}$$

This is considerably less than the value we have inferred earlier for the baryons (Eq. (21)). One could even use the above equations to determine the quark mass from the free rho and Delta masses (Eqs. (3) and (7)) and would obtain

$$m_u \approx M(\Delta) - m(\rho) \approx 462 \text{ MeV}, \tag{29}$$

considerably more than the value from the baryons! These differences are just the outcome of our oversimplified model, where no explicit mechanism for confinement has been used. In this respect the model assumes that confinement is only operative at large separations and independent from quark masses and spins. However, it is clear that the constituent masses themselves are a reflection of the confinement mechanism [2] and therefore the values of these masses are giving us a consistency check. One should not mix baryons and mesons in the process of determining the quark masses in this naive model. Furthermore, given the pion having its Goldstone property, the inequality $(m_u)_{meson} < (m_u)_{baryon}$ is not surprising, as the contribution of quark masses is being reduced to satisfy the Goldstone (low mass) property of the pion. This discussion hints, however, at a likely interpretation for the δ parameter and its value. If we consider the quark mass as an energy (momentum) parameter related to confinement [2], its value is telling us that the confinement properties of the in-medium nucleon are changing, and moreover *the negative sign implies* that a deconfinement process is taking place. This explanation agrees with the one hinted by the ε parameter.

The color hyperfine constants, obtained from the mesons and baryons under consideration, are more stable than the quark masses themselves. Thus, using Eqs. (2) and (3),

$$\left(\frac{a}{m_u^2}\right)_{meson} \approx \frac{m(\rho) - m(\pi)}{4} \approx 158 \text{ MeV}, \tag{30}$$

in agreement with the value obtained in Eq. (26) within a 7%.

Using the baryon parameters for the free and nuclear cases, we can conclude that

$$m^*(\rho) - m^*(\pi) > m(\rho) - m(\pi). \tag{31}$$

While $m^*(\rho)$ increases compared to $m(\rho)$, $m^*(\pi)$ drops strongly in nuclei according to these considerations. There is some evidence [17] of this behavior of $m^*(\rho)$ on the lattice, while the dropping of $m^*(\pi)$ is reminiscent of the nuclear behavior as a *chiral filter* [25] in the Brown-Rho approach.

3 The Skyrmion Approach

3.1 Free Baryons: the large N scaling

Let us examine the baryon interval problem from the Skyrmion approach, where the crucial idea is the generalization of QCD to N colors, as was originaly proposed by 't Hooft [19] and Witten [20]. In large-N QCD, there is a systematic expansion of contributions to baryon properties in powers of $\frac{1}{N}$. The hope here is, in Witten's words, *the* $N = 3$ *theory may be qualitatively and quantitatively close to the large* N *limit.* It is also possible to connect this large N limit to the results of the quark model in the limit of large number of colors [21].

Let us start by quoting some well-known results to set the scales of various quantities of interest to us, obtained by Adkins, Nappi and Witten (ANW) [22]. We begin with the Skyrme model Lagrangian [3, 4],

$$\mathcal{L} = \frac{F_\pi^2}{16} Tr(\partial_\mu U \partial^\mu U^+) + \frac{1}{32e^2} Tr[(\partial_\mu U)U^+, \partial_\nu U)U^+]^2, \tag{32}$$

where U is the usual SU(2) matrix of fields, F_π is the pion decay constant and the dimensionless parameter e controls the strength of the last term, the Skyrme term, needed to stabilize the soliton.

The scalings of F_π and e in number of colors, N, are given by

$$F_\pi^2 \sim N, \quad \frac{1}{e^2} \sim N, \tag{33}$$

the symbol $\sim$ implying hereafter *scales as*. (In the ANW analysis the values of the parameters used were $e = 5.45,\ F_\pi = 129$ MeV.)

The skyrmion mass is given by

$$M = \frac{\pi}{2}\, F_\pi^2\, r_0\, \mathcal{I}(\mathcal{A}), \tag{34}$$

where

$$\mathcal{I} = \int_{-\infty}^{\infty} d\tau \left[e^\tau \left(\left(\frac{d\Theta}{dt}\right)^2 + 2(\sin\Theta)^2 \right) + \mathcal{A} e^{-\tau} (\sin\Theta)^2 \left(\left(\frac{d\Theta}{dt}\right)^2 + \frac{1}{2}(\sin\Theta)^2 \right) \right] \tag{35}$$

and

$$\mathcal{A} = \frac{4}{F_\pi^2 e^2 r_0^2}, \tag{36}$$

$\tau = \ln \frac{r}{r_0}$, Θ is the so called chiral angle, and r_0 is a suitable scale parameter [23]. We get from ANW:

$$M = 36.5\, \frac{F_\pi}{e} \sim N. \tag{37}$$

The rotational energy from the quantization of the skyrmion is given by the moment of inertia

$$\lambda = \frac{2}{3}\, \pi\, F_\pi^2 r_0^3\, \mathcal{J}(\mathcal{A}) \sim N. \tag{38}$$

Here $\mathcal{J}$ is the integral [23]

$$\mathcal{J} = \int_{-\infty}^{\infty} d\tau (\sin\Theta)^2 \left[1 + \mathcal{A} \left[\left(\frac{d\Theta}{dt}\right)^2 + \frac{(\sin\Theta)^2}{r^2} \right] e^{-2\tau} \right] e^{-3\tau}, \tag{39}$$

These details are useful for our later discussions.

In terms of λ, the masses of the nucleon and the Delta as free hadrons are given by

$$M(N) \approx M + \frac{3}{4}\,\frac{1}{2\lambda} \sim N + \mathcal{O}(\frac{1}{N}), \tag{40}$$

$$M(\Delta) \approx M + \frac{15}{4}\,\frac{1}{2\lambda} \sim N + \mathcal{O}(\frac{1}{N}). \tag{41}$$

Thus, the difference between them is given by

$$\Delta M = M(\Delta) - M(N) \sim \frac{1}{\lambda} \sim \frac{1}{N}. \tag{42}$$

One could even optimistically anticipate that the Casimir and other subleading corrections would drop out in the difference [24].

3.2 Baryons in the medium: scaling parameters

We shall start from the known structure of the effective Lagrangian at low energy and zero density (temperature), given by the theory of skyrmions (32). Our discussion for complex nuclei will proceed as follows: if we increase the density (temperature) of the nucleus (i.e., of the hadronic matter), the properties of the vacuum should change. In the Skyrme model modified for the nuclear medium the two relevant parameters, F_π and e will change [25]. We work in the chiral limit ($m_\pi = 0$), which can still be taken in a situation affected by the increase in the hadronic density [26] and/or temperature [27]. We focus here only on the nucleon and the Delta in the nuclear medium.

In the Skyrme model, the baryonic interval is inversely proportional to the moment of inertia, Eq.(42), which is given in terms of the Skyrmion profile through a complicated integral, Eq. (39), where the dependence on the relevant parameters is complex. We next prove that the medium dependence of the moment of inertia can be related to that of g_A. Thus, the model establishes a relation between the baryonic interval and g_A. This relation has important experimental implications which we shall analyze.

The density (temperature) scaling properties affect the skyrmion profile, since, for the soliton configuration in the hedgehog form, one has a unique solution for a given value of $\mathcal{A}$ defined in Eq. (36). This solution satisfies the following scaling law [23, 28]

$$\Theta_{\mathcal{A}'}(\tau) = \Theta_{\mathcal{A}}\left(\tau - \frac{1}{2}\,\ln\frac{\mathcal{A}'}{\mathcal{A}}\right). \tag{43}$$

For a conserved axial current, g_A is determined by the asymptotic behavior of the soliton solution,

$$\lim_{\tau\to\infty} \Theta(\tau) \to \alpha(\mathcal{A})e^{-2\tau}, \tag{44}$$

and is given by the residue at the pion pole

$$g_A \sim 2\pi\alpha(\mathcal{A})F_\pi^2 r_0^2. \tag{45}$$

In principle, this relation holds only for the soliton. The physical g_A (see [22]) differs from this one by numerical color-dependent factors, which will cancel in the ratios.

Using the previous set of equations, we obtain

$$M(\mathcal{A}) \sim \sqrt{g_A}\, F_\pi \,\frac{\mathcal{I}(\mathcal{A})}{\sqrt{\alpha(\mathcal{A})}}, \tag{46}$$

and

$$\lambda(\mathcal{A}) \sim \frac{(\sqrt{g_A})^3}{F_\pi}\,\frac{\mathcal{J}(\mathcal{A})}{(\sqrt{\alpha(\mathcal{A})})^3}, \tag{47}$$

The scaling is determined by

$$\frac{\mathcal{I}(\mathcal{A}')}{\mathcal{I}(\mathcal{A})} = \left(\frac{\mathcal{J}(\mathcal{A}')}{\mathcal{J}(\mathcal{A})}\right)^{\frac{1}{3}} = \left(\frac{\alpha(\mathcal{A}')}{\alpha(\mathcal{A})})\right)^{\frac{1}{2}}, \tag{48}$$

and therefore all of the nuclear medium dependence will be given by

$$M(\mathcal{A}) \sim \sqrt{g_A}\, F_\pi, \tag{49}$$

and

$$\lambda(\mathcal{A}) \sim \frac{(\sqrt{g_A})^3}{F_\pi}. \tag{50}$$

The mass equation and the N dependence suggest that the two chosen parameters, g_A and F_π, scale according to

$$F_\pi \sim \sqrt{g_A}. \tag{51}$$

We now use this rule to come to the following scaling laws:

$$M \sim g_A, \tag{52}$$

and

$$\Delta M \sim M(\Delta) - M(N) \sim \frac{1}{\lambda} \sim \frac{1}{g_A}, \tag{53}$$

which lead, in the case of hadronic matter, to

$$M^* \sim g_A^*, \tag{54}$$

and

$$\Delta M^* \sim \frac{1}{g_A^*}. \tag{55}$$

This yields the scaling rule for the mass of the the nucleon and Delta in the nuclear medium. In particular, Eqs. (17) and (19) imply

$$g_A > g_A^*. \tag{56}$$

Thus, the experimental results on the baryonic interval *imply, in the leading order in* N, that g_A is quenched in the nuclear medium [31], a subject of great topical interest in QCD.

We should point out that the experimental situation on the quenching of g_A in the nuclear medium is far from settled, despite the long history of the subject [31]. Here we are pointing out a new angle to this problem, via its novel connection to the baryonic interval.

3.3 A numerical analysis of the Skyrmion scaling in the Delta-Hole model

According to the Δ-hole model ([8]-[10])

$$\delta g = \frac{g_A}{g_A^*} \approx 1 + \frac{4}{9}\left(\frac{f^*}{m_\pi}\right)^2 \frac{2}{M(\Delta) - M(N)}\, g_0'\, \rho, \tag{57}$$

where the ratio of the Watson-Lepore constants for the nucleon is given by $\frac{f^*}{f} \approx 4$, $g_0' \approx 0.7 \pm 0.1$ is the Landau-Migdal parameter and ρ is the nuclear density. With these values,

$$\delta g \approx 1 + (0.273 \pm 0.039)\,\frac{\rho}{\rho_0}, \tag{58}$$

ρ_0 is the nuclear matter density. We use this equation to show in Tables 1 and 2 how the skyrmionic mass and the baryonic interval change with density in this model.

Table 1: Skyrmion mass ratio $\frac{M^*}{M}$ as a function of nuclear density (normalized to nuclear matter density) for three values of the Landau-Migdal parameter $g_0' = 0.7 \pm 0.1$.

$\frac{\rho}{\rho_0}$	0.0	0.2	0.4	0.6	0.8	1.0
0.6	1.0	.955	.914	.877	.889	.810
0.7	1.0	.949	.902	.859	.821	.786
0.8	1.0	.942	.889	.842	.800	.762

It is interesting to note at this point that the results showed in Table 1 allow us to explain in a qualitative fashion the observed behavior of the masses in the medium.

Table 2: Baryonic interval ratio $\frac{\Delta M^*}{\Delta M}$ as a function of nuclear density (normalized to nuclear matter density) for three values of the Landau-Migdal parameter $g_0' = 0.7 \pm 0.1$.

$\frac{\rho}{\rho_0}$	0.0	0.2	0.4	0.6	0.8	1.0
0.6	1.0	1.047	1.094	1.140	1.187	1.234
0.7	1.0	1.054	1.109	1.164	1.218	1.273
0.8	1.0	1.062	1.125	1.187	1.250	1.312

Once Eqs.(40) and (41) are scaled, they lead to expressions of the form

$$\sim g_A^* + \frac{\kappa}{g_A^*}, \tag{59}$$

where $\kappa(\Delta) >> \kappa(\mathrm{N})$. Thus, in the nucleon case, the first term (which decreases with density) starts dominating, while in the Δ case, the diverse tendencies tend to cancel. Ultimately the second term should dominate and both masses should increase with density. In order to do a more quantitative discussion one should include the missing terms, Casimir energy and other subleading corrections [24]. Unfortunately, we do not yet have reliable estimates of them.

4 Conclusions

We have analyzed the medium dependence of the properties of hadrons in two different schemes with the same physical input: *the nuclear medium dependence implies a change in the properties of the vacuum which translates into a scaling (density and/or temperature dependence) of the free model parameters.*

In the quark model, the hadron mass intervals studied are connected by the the color hyperfine interaction. Our analysis indicates that the fundamental parameters of the model, m_u and a, or, equivalently, the confinement scale and α_S, change, signalling a deconfinement process in the medium. This scenario leads naturally to a change of the properties of the hadrons, e.g., a *renormalization* of the strong, electromagnetic and weak vertices in the nuclear medium [1]. This is of great topical interest in our understanding of nuclear QCD properties.

[1] For example, the magnetic moments in the naive quark model are inversely proportional to the quark masses. Therefore, the electromagnetic couplings should be reduced in the medium. A similar analysis can be done for all other interactions looking at the parameter dependence of the naive model formulas[2, 11].

The same reasoning has been applied to the skyrmion model. The change of the baryonic interval from the free value to that in nuclei produces a change in the parameters of the model F_π and e. This scaling is complex, since it enters into the profile function of the hedgehog. We have avoided a complex parameter fitting procedure in nuclear medium, and have taken the implications of the model at the qualitative level. We have thus obtained a relation between two physical intervals of our interest. In our analysis, the nuclear quenching of g_A is directly related to the quenching of the moment of inertia and therefore to the growth of the baryonic interval in the nuclear medium. From the physical point of view, the quenching of g_A in nuclei is again a manifestation of deconfinement, since the nucleon in the nuclear medium is closer to a chirally symmetric phase. Recalling Adkins *et al.* [22], observed hadron characteristics are calculated by means of the profile function and their explicit dependence on the parameters. Thus all of them have a calculable Large-N scaling behavior. Moreover, many of these quantities can be directly related to the moment of inertia and therefore their medium behavior can be obtained directly from the above expressions [2]. Thus the change of the baryon mass interval in the medium leads to a *renormalization* of the strong, electromagnetic and weak vertices in nuclei, through the scaling of the parameters and the dictates of large N behavior.

In summary, the present investigation has shown that two different models of hadronic intervals suggest one and the same phenomenon: partial deconfinement in the nuclear medium. It is interesting that they are found from *different, but complementary, perspectives, both inspired by QCD.* The quark model emphasizes approximate color dynamics, while the Skyrme model draws the attention to chiral dynamics[3]. Moreover, we have shown that the in-medium properties change in a very specific way determined by the parameters of the theory and thus, the *renormalization* of the interactions lead to experimentally testable phenomena which open new avenues of QCD exploration in nuclei not anticipated by the conventional many-body theory.

More theoretical investigations are necessary to provide accurate experimental scenarios where the in-medium properties advanced in this investigation are envisaged. We are aware of one work along these lines completed recently [33] in the context of the ω-meson. There have been also recent studies of these issues in the context of the

[2]For example $\mu_{N\Delta} \sim \mu_p - \mu_n \sim \lambda$, thus this much-studied electromagnetic transition rate[32] will be quenched in the nuclear medium. The strong coupling of nucleons, Deltas and pions are related to g_A through appropriate Goldberger-Treiman relation [29] and therefore also subject to quenching.

[3]A beautiful example of the complementarity of the two approaches is related to g_A. In the quark model with three colors, g_A is independent of the mass interval and therefore remains unquenched. In the Skyrme model, chirality bridges them and therefore leads to the quenching in nuclei in the leading order of N.

QCD sum rules for nuclei [34]. Future works should clarify relations between them and QCD-inspired model studies such as ours. It is apt to end here with a plea [34]: "Ask not what nuclear physics can do for QCD. Ask what QCD can do for nuclear physics!"

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