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# Quark Effects in Deformed Bags

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**Abstract:** Modification of the Schmidt expressions for the magnetic moment of nuclei with closed core+one nucleon in the hybrid quark model framework, has been discussed when the nucleonic bags get deformed. The results obtained for the probability of the deformed bag formation from the experimental magnetic moments of nuclei A=13, 17, 29, 33, 41 show large values.

**Keywords:** Schmidt values, magnetic moments of mirror nuclei with closed core+one nucleon, hybrid quark model (HQM), six-quark cluster formation effects and probabilities of the deformation parameters of nucleonic bags.

## 1. Introduction

It is now well known that hadrons are composite particulars with quarks as elementary constituents and in the region where two hadrons overlap each other; the internal structure of hadrons is expected to play a vital role. A number of deep inelastic scattering experiments of leptons and neutrino of protons support the quark structure of hadrons.

Our calculations are based on a Hybrid Quark Model (HQM). "In this model the nuclear matter has two phases. Two nucleons maintain their identity as long as the distance between them is greater than a certain cut of radius $r_0$. For distances smaller than $r_0$ the two baryons overlap and form a six-quark bag". Thus HQM retains the quantum chromodynamics (QCD) at short distances.

In continuation with the previous work[1] where we have analysed the effect of additional quark degrees of freedom in nucleons on the magnetic moments of nuclei with closed shell+one nucleon. We have estimated the correction to the magnetic moment of mirror pair of nuclei with A = 13, 17, 29, 33, 41, in the framework of HQM discussed earlier.

Deviation from the Schmidt values of the magnetic moments for mirror nuclei having closed core +N configuration $\left({}^{13}_{6}C \sim {}^{14}_{7}N; {}^{17}_{8}O \sim {}^{17}_{9}F; {}^{29}_{14}Si \sim {}^{29}_{15}P; {}^{33}_{16}S \sim {}^{33}_{17}Cl; {}^{41}_{20}Ca \sim {}^{41}_{21}Sc\right)$ discussed in our previous paper illustrates:

(i) The quark bag formation effect contributes significantly and tends to increase the magnetic moment of nuclei from their single particle values.

(ii) The six-quark cluster formation effect together with the other corrections can account for the observed discrepancy with the experimental data.

It has long been recognized that there are several other mechanisms which play important role in explaining the deviation of magnetic moments from the Schmidt values. These are the corrections arising due to mixing of configurations, meson-exchange current, core-polarisation, deformation etc. The quark bag formation takes place for small inter-nuclear distance and one-pion correction are dominant for large distances; these two effects are complimentary to each other and should be added in the estimation of correction. The correction due to configuration mixing is caused due to intermingling of configurations of the nucleonic states and contributes over and above the correction due to quark degrees of freedom. If these corrections are added to the quark cluster correction, discrepancy with the experimental data decreases in some of the nuclei $\left({}^{13}_{6}C, {}^{13}_{7}N, {}^{29}_{14}Si, {}^{41}_{20}Ca, {}^{41}_{21}Sc\right)$.

The effect of quark structure of nucleons on nuclear properties has been studied by certain other methods as well[2] has shown that the experimental data on the magnetic moments of ${}^{3}H \sim {}^{3}He$ pair can be obtained if nucleonic bags consisting of three quarks are considered to be deformed.

In the present work we have tried an alternative approach to explain the observed deviation from the Schmidt value by allowing the nucleonic bags to get deformed with large D-state admixture in it, to estimate the deformation parameters of nucleonic bags for mirror pair of nuclei with A = 13, 17, 29, 33, 41 which reproduce the observed experimental values for nuclei's $\left({}^{13}_{6}C \sim {}^{13}_{7}N; {}^{17}_{8}O \sim {}^{17}_{9}F; {}^{29}_{14}Si \sim {}^{29}_{15}P; {}^{33}_{16}S \sim {}^{33}_{17}Cl; {}^{41}_{20}Ca \sim {}^{41}_{21}Sc\right)$.

## 2. Formalism

The MIT bag model[3,4] and its modifications[5,6,7] have been very successful in describing and explaining the properties of hadrons. In most of the bag model studies the bag is assumed to have a spherically symmetric shape. In order to account for certain discrepancies with the experimental data, some of the authors[7-11] have considered the formation of deformed bags with large D-state admixture in it.

The formation of the deformed bags can be understood in the following way:

i) As soon as the bag is populated by quarks in excited state or by gluons, these particles will exert a non-isotropic pressure on the bag surface and thus the bag gets deformed.
ii) Moreover, whenever hadrons come very close together, that is the distances typically of the size of hadron; they may get polarized and deformed.
iii) The magnetic moment of a deformed nucleonic bag consisting of three quarks is different than the intrinsic magnetic moment of free nucleon and is dependent on the D-state admixture parameter.

For single nucleons the magnetic moments can be expressed as[2],

(2.1) $$\mu(n) = -\frac{2}{3}\left[1 - P_D(N)\right]\mu_q$$

(2.2) $$\mu(p) = \left[1 - P_D(N)\right]\mu_q$$

$\mu_q = e\hbar / 2m_q c$ ,where $m_q$ is the mass of the quark and $P_D(N)$ is the probability of D-state admixture in the nucleon bag. If the nucleon bags are deformed, the Schmidt value of the magnetic moments for a pair of mirror nuclei in the quark picture can be expressed as,

For neutron rich Nucleus,

(2.3) $$\mu\left({}^{A+1}_{z}X\right) = \pm\frac{2J}{(2l+1)}\left[1 - P_D\left({}^{A+1}_{z}X\right)\right]\mu_q \quad \Big| \; J = l \pm 1/2$$

For proton rich Nucleus,

(2.4) $$\mu\left({}^{A+1}_{z+1}Y\right) = J\left[1 \pm \frac{(-1)}{(2l+1)}\right] \pm \frac{2J}{(2l+1)}\left\{\left[1 - P_D\left({}^{A+1}_{z+1}Y\right)\right]\right\}\mu_q$$

$$\Big| \; J = l \pm 1/2$$

Where $P_D\left({}^{A+1}_{z}X\right)$ and $P_D\left({}^{A+1}_{z+1}Y\right)$ refer to the deformation of the odd nucleon for a particular nucleus. For proton rich nucleus the contribution from the intrinsic part can be expressed as

(2.5) $$\mu'\left({}^{A+1}_{z+1}Y\right)=\mu'\left({}^{A+1}_{z+1}Y\right)-J\left[1\pm\frac{(-1)}{(2l+1)}\right] \Big|\ \mathrm{J}=l\pm ½$$

The deformation parameter $P_D$ for a particular nucleus can calculated from the known experimental values of the magnetic moments of nuclei using the following expressions

(2.6) $$\frac{\mu\left({}^{A+1}_{z}X\right)}{\mu(n)}=\pm\frac{3J}{(2l+1)}\left[\frac{1-P_D\left({}^{A+1}_{z}X\right)}{1-P_D(N)}\right] \Big|\mathrm{J}=l\pm ½$$

(2.7) $$\frac{\mu\left({}^{A+1}_{z+1}Y\right)}{\mu(p)}=\pm\frac{2J}{(2l+1)}\left[\frac{1-P_D\left({}^{A+1}_{z+1}Y\right)}{1-P_D(N)}\right] \Big|\ \mathrm{J}=l\pm ½$$

The ratio of the deviations $(\delta)$ in the magnitude of the magnetic moments from the intrinsic magnetic moment of free nucleons in mirror nuclei is defined as,

(2.8) $$\delta=\frac{\delta\mu\left({}^{A+1}_{z}X\right)}{\delta\mu\left({}^{A+1}_{z+1}Y\right)}=\frac{\mu\left({}^{A+1}_{z}X\right)-\mu(n)}{\mu'\left({}^{A+1}_{z+1}Y\right)-\mu(p)}$$

If magnetic moments of nuclei are expressed as in equations (2.3) and (2.5), the above equation can be rewritten as

(2.9) $$\delta=-\frac{2}{3}\left[\frac{\pm 2J\left[1-P_D\left({}^{A+1}_{z}X\right)\right]-(2l+1)\left[1-P_D(N)\right]}{\pm 2J\left[1-P_D\left({}^{A+1}_{z+1}Y\right)\right]-(2l+1)\left[1-P_D(N)\right]}\right]$$

## 3. Calculation and Result

An alternative approach to account for the observe deviation from the Schmidt value is to consider the formation of deformed nucleonic bags inside nuclei. Earlier studies have shown[2] that the formation of deformed nucleonic bags effect the magnetic properties of nuclei. We have estimated the probability of deformed bag formation $(P_D(A))$ from the experimental magnetic moments for nuclei with A = 13, 17,29,33,41. The results are shown in Table 1.

We have also calculated the magnitudes of the ratio of the deviation in the magnetic moments from the single nucleon values from equations (2.8), (2.9). The results are displayed as the ratio of the deviation for the mirror pair in Table 2 and compared with the corresponding experimental values.

**Table 1** Probability of deformed bag formation $(P_D(A))$ in light nuclei with $A = 13, 17, 29, 33, 41$.

| A | Nucleus | $P_D(A)$ |
|---|---|---|
| 13 | ${}^{13}_{6}C_7$ | 0.1739 |
| | ${}^{13}_{7}N_6$ | 0.2000 |
| 17 | ${}^{17}_{8}O_9$ | 0.2576 |
| | ${}^{17}_{9}F_8$ | 0.2683 |
| 29 | ${}^{29}_{14}Si_{15}$ | 0.7832 |
| | ${}^{29}_{15}P_{14}$ | 0.6680 |
| 33 | ${}^{33}_{16}S_{17}$ | 0.5793 |
| | ${}^{33}_{17}Cl_{16}$ | 0.5306 |
| 41 | ${}^{41}_{20}Ca_{21}$ | 0.3747 |
| | ${}^{41}_{21}Sc_{20}$ | 0.3468 |

**Table 2** Ratio of the deviation of deformed magnetic moments for the mirror pair $A = 13, 17, 29, 33, 41$. $\delta_{Exp}$ and $\delta_{Cal}$ are the experimental and calculated values of the deviation respectively.

| A | Nucleus | $\delta_{Exp}^{*}$ | $\delta_{Cal}$ |
|---|---|---|---|
| 13 | ${}^{13}_{6}C_{7} \sim {}^{13}_{7}N_{6}$ | -0.6915 | -0.6726 |
| 17 | ${}^{17}_{8}O_{9} \sim {}^{17}_{9}F_{8}$ | -0.2838 | -0.2750 |
| 29 | ${}^{29}_{14}Si_{15} \sim {}^{29}_{15}P_{14}$ | -0.8745 | -0.8503 |
| 33 | ${}^{33}_{16}S_{17} \sim {}^{33}_{17}Cl_{16}$ | -0.6623 | -0.6478 |
| 41 | ${}^{41}_{20}Ca_{21} \sim {}^{41}_{21}Sc_{20}$ | -0.8833 | -0.8585 |

* Experimental values of magnetic moments used in calculating $\delta_{Exp}$ are from Raghavan[12].

## 4. Conclusion

For free nucleon $P_D(N)$ is 1/4, but this value gets modified inside the nuclear medium. The European Muon Collaboration effect[13-15] results indicate that there is an increase in the confinement size of the nucleons in the nuclear medium. If we accept this picture, then $P_D(A) < P_D(N)$. In a deformed bag there is a larger surface area in the flat region than at the edges. If the pull on the surface is uniform, greater expansion will take place perpendicular to the flat part .and so the deformation will decrease with increasing A. This trend is not reflected in our results. The D-state probabilities are particularly large for $A = 29, 33$. These are also the nuclei for which the experimental magnetic moments differ largely from the Schmidt values. This is probably indicative of the fact that the simple picture of deformed bags is not suitable for these nuclei. Thus the probability of deformed bag from experimental data found that, these values are quite large.

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