Magnetic moments of cascade baryons with strange sea in statistical model

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Introduction

Study of hadrons can help to enrich our knowledge of its structure. Various recent experimental facilities at BASE, COMPASS etc. have provided opportunities for measurements of hadronic properties with an additional strangeness degree of freedom and search for exotic particles. Experimentally, at present magnetic moments of Δ^{++} , Δ^{0} and Ω^{-} are known. Magnetic moments of decuplet particles have not been measured experimentally because the particles decay strongly and thus do not live long enough. The present work analyses the contribution of sea-quarks to magnetic moment of cascade baryons of $J^P = 3/2^+$ decuplet. For this, the methodology is based on the statistical model presented in ref. [1].The results are compared with the predictions of other models.

Theoretical Framework

The statistical model had been successfully predicted and explained the magnetic moments and other properties of a nucleonic system [1].The model is based on assumption of hadrons as an ensemble of quark-gluon Fock states so that each Fock state shares some part of total probability associated with quark-gluon Fock states. The Fock states include different sub-processes like etc. $q \Leftrightarrow qg, g \Leftrightarrow q\bar{q}, g \Leftrightarrow gg$

The methodology is based on framing a suitable wave-function in such a way that each term in the wave-function contains suitable combinations of valence and sea quarks such that it satisfies the anti-symmetrisation and spin 3/2, flavour decuplet, color singlet of baryonic system.

$$\left|\Phi_{\frac{3}{2}}^{\uparrow}\right\rangle = \frac{1}{N}[a_0 \phi_1^{(\frac{3}{2})\uparrow} H_0 G_1 + b_1[\phi_1^{(\frac{3}{2})} \otimes H_1]^{\uparrow} G_1 + b_8[\phi_1^{(\frac{1}{2})} \otimes H_1]^{\uparrow} G_8 + d_1[\phi_1^{(\frac{3}{2})} \otimes H_2]^{\uparrow} G_1 + d_8[\phi_8^{(\frac{1}{2})} \otimes H_2]^{\uparrow} G_8]$$

$$where N^2 = a_0^2 + b_1^2 + b_8^2 + d_1^2 + d_8^2$$

$a_0$term describe a spin 3/2 of q^3 coupled to a spin 0 (scalar sea) , b_1:b_8 describes vector sea and d_1;d_8 signifies tensor sea. To calculate the coefficients, the first step is to use principle of detailed balance [2] in order to find the flavor probability of each Fock state. The principle assumes that every Fock state should be balanced by other Fock states. Various sub processes included in the transition processes are:

The expressions for the rates of transitions between any two processes can be written as:

1. When both the $q \Leftrightarrow qg, g \Leftrightarrow gg$ processes are included:

$$\frac{\rho_{i,j,l,k}}{\rho_{i,j,l,k-1}} = \frac{(3+2i+2j+2l+k-1)}{(3+2i+2j+2l)k + \frac{k(k-1)}{2}}$$

where i refer to $u\bar{u}$ pairs, j refer to $d\bar{d}$, l refers to $s\bar{s}$ and k refers to no. of gluons.

2. When the processes $g \Leftrightarrow s\bar{s}$ are included: The exchanges between the gluons and strange quark anti-quark pair are limited due to large mass of strange quark. Gluon must possess the free energy at least greater than mass of strange quark. Using free energy distributions for gluons, the expression for transition rates between gluon and strange quark anti-quark pair can be written as:

$$\frac{\rho_{i,j,l,k}}{\rho_{i,j,l+k,0}} = \frac{k(k-1)...1(1-C_0)^{n-2l-1}...(1-C_{l-1})^{n-k-2}}{(l+1)(l+2)....(l+k)(l+k+1)}$$

All expressions in terms of $\rho_{0,0,0,0}$ for Cascade particles are:

Baryon	Expression
Ξ^{*-}	$\frac{\rho_{i,j,l+k,0}}{\rho_{0,0,0,0}} = \frac{2}{i!i!j!(j+1)!(l+k)!(l+k+2)!}$
Ξ^{*0}	$\frac{\rho_{i,j,l+k,0}}{\rho_{0,0,0,0}} = \frac{2}{i!(i+1)!j!j!(l+k)!(l+k+2)!}$

The normalization condition $\sum_{i,j,k,l} \rho_{i,j,k,l} = 1$ gives the individual probabilities. The statistical method involves the computation of individual multiplicities denoted in the form of various ratios.

$$\rho_{\frac{1}{2}1}[\rho_{88}, \rho_{10\overline{10}}] = c[2,1] = d[\frac{1}{96}, \frac{1}{300}]$$

$$\rho_{\frac{1}{2}2}[\rho_{11}, \rho_{88}] = 2c[1,2] = 2d[\frac{1}{5}, \frac{1}{160}]$$

The product probability ratios are expressed in the form of common parameter "c" and "d". These coefficients provide us the contribution of sea.

States	H_0G_1	H_1G_1	H_1G_8	H_2G_1	H_2G_8
$\vert gg\rangle$	0.01768	0	0.000184	0.003536	0.000221
$\vert u\bar{u}g\rangle$	0.001667	0	0.0000694	0.000667	0.0000833
…..	…..	…..	…..	…..	…..

Table for "nc"

Magnetic Moments of J^P =3/2^+ Cascade baryons

Moving charged particle induces current which in result produces magnetic moment 'μ' given by:

$$\mu = \frac{e}{2m}(L+S)$$

As in our study L=0 so $\mu = \frac{e}{2m}.S$

In the absence of orbital motion of quarks, for a spin 1/2 charged particle, the magnetic moment operator over a baryonic wavefunction can be defined as: $\mu_B = \sum_{i=u,d,s} \langle B|\frac{e_i\sigma_z^i}{2m}|B\rangle$

$$\left\langle \Phi^{\uparrow}_{\frac{3}{2}} \middle| \hat{O} \middle| \Phi^{\uparrow}_{\frac{3}{2}} \right\rangle = \frac{1}{N}[\left\langle \phi_1^{(\frac{3}{2})\uparrow} H_0G_1 \middle| \hat{O} \middle| \phi_1^{(\frac{3}{2})\uparrow} H_0G_1 \right\rangle +$$
$$\left\langle [\phi_1^{(\frac{3}{2})} \otimes H_1]^{\uparrow} G_1 \middle| \hat{O} \middle| [\phi_1^{(\frac{3}{2})} \otimes H_1]^{\uparrow} G_1 \right\rangle +$$
$$\left\langle [\phi_1^{(\frac{1}{2})} \otimes H_1]^{\uparrow} G_8 \middle| \hat{O} \middle| [\phi_1^{(\frac{1}{2})} \otimes H_1]^{\uparrow} G_8 \right\rangle +$$
$$\left\langle [\phi_1^{(\frac{3}{2})} \otimes H_2]^{\uparrow} G_1 \middle| \hat{O} \middle| [\phi_1^{(\frac{3}{2})} \otimes H_2]^{\uparrow} G_1 \right\rangle +$$
$$\left\langle [\phi_8^{(\frac{1}{2})} \otimes H_2]^{\uparrow} G_8 \middle| \hat{O} \middle| [\phi_8^{(\frac{1}{2})} \otimes H_2]^{\uparrow} G_8 \right\rangle$$

For Ξ^{*-} , the expression for the magnetic moments can be written as:

$$\Phi^{\uparrow}_{\frac{3}{2}} = \frac{1}{N^2}[a_0^2(30\mu_s + 15\mu_d) +$$
$$b_1^2(22\mu_s + \mu_d) + b_8^2(22\mu_s + \mu_d) +$$
$$d_1^2(6\mu_s + 3\mu_d) + d_8^2(3\mu_s + 1.5\mu_d)]$$

The results of our work are compared with the predictions of other models in the table shown below:

Other Models	$\mu(\Xi^{*-})$	$\mu(\Xi^{*0})$
CQSM[3]	-2.40	0.09
QCDSR[4]	-1.51	-0.69
NQM[5]	-2.2	-0.63
RQM[6]	-2.41	-0.60
This Work	**-2.81**	**-0.29**

Results and Conclusions

We apply statistical approach to write the wave functions for cascade baryons having valence and sea quarks and gluons, which provides us a platform tofind the contribution of all types of Fock states. The detail balance principlewhich assumes that every Fock state should be balanced by other Fock states is used to find the coefficients of the wavefunction. We calculate the magnetic moments of decuplet Cascade baryons using a constraint where sea can have limited numbers of strange sea quarks. The results are matching with the other theoretical models[3-6]. Recent experiments are motivated to inspect the magnetic moments of decuplet baryons by the predictions of our and other models, thereby, providing a good understanding for baryon structure.

References

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