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χPT) [11-15], relativistic quark model (RQM) [16, 17], non relativistic quark model (NRQM) [18], QCD sum rules (QCDSR) [6, 7, 19, 20], chiral quark soliton model (χQSM) [21, 22], chiral constituent quark model (χCQM) [23], chiral bag model (χB) [24], cloudy bag model [25], quenched lattice gauge theory [26] etc., have been tried, but with partial success.

However, the six dimensional hyper central quark model with coulomb plus power potential ($hCPP_\nu$) is found to be successful in predicting the masses and magnetic moments of baryons in the heavy flavour sector (baryon containing charm or beauty quarks) [27, 28]. Thus, it has prompted us to extend the $hCPP_\nu$ model in the light flavour baryonic sector. Accordingly, in this paper we compute the masses and magnetic moments of octet and decuplet baryons in the u, d, s sector. In section 2 the hypercentral scheme and a brief introduction of $hCPP_\nu$ potential employed for the present study are described. Section 3 describes the computational details of the magnetic moment of octet and decuplet baryons. In section 4 we discuss our results while comparing with other theoretical predictions and experimental results.

MATERIALS AND METHODS

Hypercentral Scheme for Baryons

Quark model description of baryons is a simple three body system of interest. Generally the phenomenological interactions among the three quarks are studied using the two-body quark potentials as in the case of the Isgur Karl Model [29], the Capstick and Isgur relativistic model [30, 31], the Chiral quark model [32], the Harmonic Oscillator model [33, 34] etc. The three-body effects are incorporated in such models through two-body and three-body spin-orbit terms [27, 35]. The Jacobi Co-ordinates to describe baryon as a bound state of three constituent quarks are given by [36]

$$\rho = \frac{1}{\sqrt{2}}\left(r_1 - r_2\right); \lambda = \frac{\left(m_1 r_1 + m_2 r_2 - \left(m_1 + m_2\right) r_3\right)}{\sqrt{m_1^2 + m_2^2 + \left(m_1 + m_2\right)^2}} \qquad (1)$$

Such that

$$m_\rho = \frac{2 m_1 m_2}{m_1 + m_2}; \quad m_\lambda = \frac{2 m_3 \left(m_1^2 + m_2^2 + m_1 m_2\right)}{\left(m_1 + m_2\right)\left(m_1 + m_2 + m_3\right)} \qquad (2)$$

Here m_1, m_2 and m_3 are the constituent quark mass parameters. In the hypercentral model, we introduce the hyper spherical coordinates which are given by the angles

$$\Omega_\lambda = (\theta_\lambda, \phi_\lambda) \quad ; \quad \Omega_\rho = (\theta_\rho, \phi_\rho) \qquad (3)$$

together with the hyper radius, x and hyper angle ξ respectively as,

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$$x = \sqrt{\rho^2 + \lambda^2} \quad ; \qquad \xi = \arctan(\frac{\rho}{\lambda}) \tag{4}$$

The model Hamiltonian for baryons can now be expressed as

$$H = \frac{P_\rho^2}{2m_\rho} + \frac{P_\lambda^2}{2m_\lambda} + V(\rho,\lambda) = \frac{P_x^2}{2m} + V(x) \tag{5}$$

Here the potential $V(x)$ is not purely a two body interaction but it contains three-body effects also. The three body effects are desirable in the study of hadrons since the non-abelian nature of QCD leads to gluon-gluon couplings which produce three-body forces [37]. Using hyperspherical coordinates, the kinetic energy operator $\frac{P_x^2}{2m}$ of the three-body system can be written as

$$\frac{P_x^2}{2m} = \left(\frac{-1}{2m}\frac{\partial^2}{\partial x^2} + \frac{5}{x}\frac{\partial}{\partial x} - \frac{L^2(\Omega_\rho,\Omega_\lambda,\xi)}{x^2} \right) \tag{6}$$

Where $L^2(\Omega_\rho,\Omega_\lambda,\xi)$ is the quadratic Casimir operator of the six dimensional rotational group $O(6)$ and its eigen functions are the hyperspherical harmonics, $Y_{[\gamma]l_\rho l\rho}(\Omega_\rho,\Omega_\lambda,\xi)$ satisfying the eigenvalue relation

$$L^2 Y_{[\gamma]l_\rho l\rho}(\Omega_\rho,\Omega_\lambda,\xi) = \gamma(\gamma+4) Y_{[\gamma]l_\rho l\rho}(\Omega_\rho,\Omega_\lambda,\xi) \tag{7}$$

Here γ is the grand angular quantum number and it is given by $\gamma = 2\nu + l_\rho + l\lambda$, and $\nu = 0,1,.....$ l_ρ and l_λ being the angular momenta associated with the ρ and λ variables.

If the interaction potential is hyper spherical such that the potential depends only on the hyper radius x, then the hyper radial Schrödinger equation corresponds to the hamiltonian given by Eqn. (5) can be written as

$$\left[\frac{d^2}{dx^2} + \frac{5}{x}\frac{d}{dx} - \gamma(\gamma+4) \right] \phi_\gamma(x) = -2m\left[E - V(x)\right]\phi_\gamma(x) \tag{8}$$

Here, m is the reduced mass defined by [33]

$$m = \frac{2m_\rho m_\lambda}{m_\rho + m_\lambda} \tag{9}$$

For the present study we consider the hyper central potential $V(x)$ as the hyper coulomb plus power ($hCPP_\nu$) form similar to the one given by [27, 28, 38] as

$$V(x) = -\frac{\tau}{x} + \beta x^\nu + \kappa + V_{spin} \tag{10}$$

In the above equation the spin independent terms correspond to confinement potential as in the hyperspherical co-ordinates. It belong to a generality of potential of the form $-Ar^\alpha + \kappa r^\varepsilon + V_0$ where A, κ, α and ε are non negative constants where as V_0 can have either sign. There are many attempts with different choices of α and ε to study the hadron properties [39]. For example, Cornell potential has $\alpha = \varepsilon = 1$, Lichtenberg potential has $\alpha = \varepsilon = 0.75$. Song-Lin potential has $\alpha = \varepsilon = 0.5$ and the Logarithmic potential of Quigg and Rosner corresponds to $\alpha = 0$, $\varepsilon \to 0$ [39]. Martin potential corresponds to $\alpha = 0$, $\varepsilon = 0.1$ [39] while Grant, Rosner and Rynes potential corresponds to $\alpha = 0.045$, $\varepsilon = 0$; *Heikkilä*, *Törnqusit* and Ono potential corresponds to $\alpha = 1$, $\varepsilon = 2/3$ [40]. It has also been explored in the region $0 \le \alpha \le 1.2$, $0 \le \varepsilon \le 1.1$ of $\alpha - \varepsilon$ values [41]. So it is important to study the behavior of different potential scheme with different choices of α and ε to know the dependence of their parameters to the hadron properties. The spin independent part of potential defined by Eqn.(10) corresponds to $\alpha = 1$ and $\varepsilon = \nu$. Here τ of the hyper-coulomb, β of the confining term and κ are the model parameters. The parameter τ is related to the strong running coupling constant α_s as [27, 28]

$$\tau = \frac{2}{3} b\alpha_s \tag{11}$$

where b is the model parameter (≈ 14), $\frac{2}{3}$ is the color factor for the baryon and $\beta = m\tau$ numerically in terms of $(MeV)^{\nu+1}$ are the potential parameters as employed for the study of heavy flavour baryons [27, 28]. The strong running coupling constant is computed using the relation

$$\alpha_s = \frac{\alpha_s(\mu_0)}{1 + \frac{33 - 2n_f}{12\pi}\alpha_s(\mu_0)\ln\left(\frac{\mu}{\mu_0}\right)} \tag{12}$$

where $\alpha_s(\mu_0 = 1GeV) \approx 0.6$ is considered in the present study. To account for the mass difference between the octet and decuplet baryons, the spin dependent part of the three body interaction of Eqn. (10) is considered as [27, 35]

$$V_{spin}(x) = -\frac{1}{4}\alpha_s \frac{e^{\frac{-x}{x_0}}}{xx_0^2} \sum_{i<j} \frac{\vec{\sigma}_i.\vec{\sigma}_j}{6m_i m_j} \vec{\lambda}_i.\vec{\lambda}_j \tag{13}$$

with x_0 as the hyperfine parameter of the model. The six dimensional radial Schrodinger equation described by Eqn. (8) has been solved in the variational scheme with the hyper coloumb trial radial wave function given by [37]

$$\psi_{\omega\gamma} = \left[\frac{(\omega-\gamma)!(2g)^6}{(2\omega+5)(\omega+\gamma+4)!} \right]^{\frac{1}{2}} (2gx)^\gamma e^{-gx} L_{\omega-\gamma}^{2\gamma+4}(2gx) \tag{14}$$

The wave function parameter g and hence the energy eigen values are obtained by applying virial theorem for a chosen potential index ν.

The baryon masses are then obtained by the sum of the quark masses with the expectation value of the Hamiltonian as

$$M_B = \sum_i m_i + \langle H \rangle \tag{15}$$

For the present calculations, we have employed the same mass parameters of the light flavour quarks (m_u =338 MeV, m_d = 350 MeV, m_s = 500 MeV) as used in [27]. We fix other parameters (b of Eqn.(11) and x_0 of Eqn.(13)) of the model for each choices of ν so as to reproduce the experimental center of weight (spin-average mass) and hyper fine splitting of the octet decuplet baryons. The procedure is repeated for different choices of ν and the computed masses of octet and decuplet baryons are listed in Table (1) and Table (2) respectively.

EFFECTIVE QUARK MASS AND MAGNETIC MOMENTS OF LIGHT BARYONS

Within the baryons the mass of the quarks may get modified due to its binding interactions with other two quarks. We account this bound state effect by defining an effective mass to the bound quarks, m_i^{eff} as given by [27, 28, 38]

$$m_i^{eff} = m_i \left(1 + \frac{\langle H \rangle}{\sum_i m_i} \right) \tag{16}$$

such that $M_B = \sum_{i=1}^{3} m_i^{eff}$.

Now the magnetic moment of the baryons are computed in terms of its quarks spin-flavour wave function of the constituent quarks as

$$\mu_B = \sum_i \left\langle \phi_{sf} \mid \mu_i \vec{\sigma}_i \mid \phi_{sf} \right\rangle \tag{17}$$

where

$$\mu_i = \frac{e_i}{2 m_i^{eff}} \tag{18}$$

Here e_i and σ_i represents the charge and the spin of the quark constituting the baryonic state and $\left|\phi_{sf}\right\rangle$ represents the spin-flavour wave function of the respective baryonic state as listed in [42]. The computations are repeated for the different choices of the flavour combinations of qqq (q = u, d, s). The computed magnetic moments of the octet and decuplet baryons are listed in Table (3) and (4) respectively.

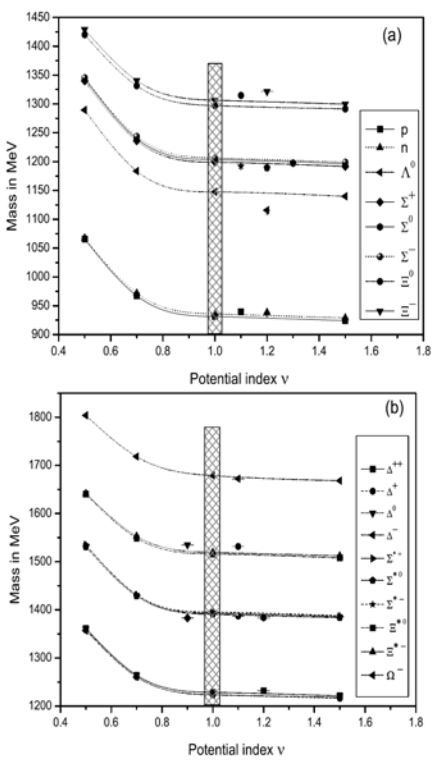

Fig. 1 Variation of octet (a) and decuplet (b) baryon masses with respect to potential index ν . The experimental masses of these baryons are shown with error bar. The shaded region show minimum root mean square deviation with experimental results.

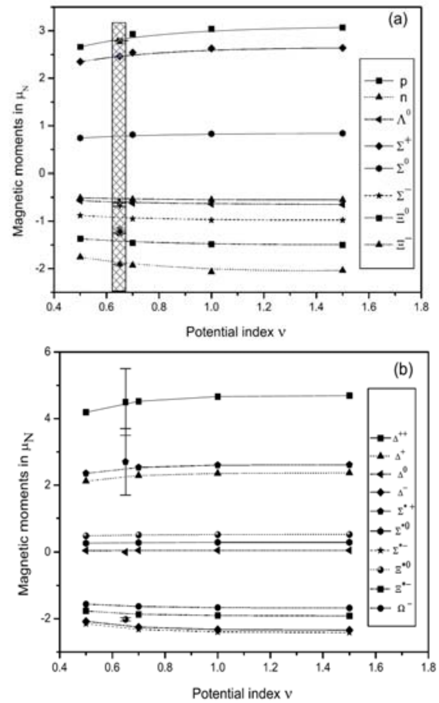

Fig. 2 Behaviour of the magnetic moments of octet and decuplet baryons with respect to potential index ν . The known experimental values are shown with error bar. The shaded region show minimum root mean square deviation with experimental results.

RESULTS AND DICUSSION

The masses of octet and decuplet baryons in the hyper spherical coulomb plus power potential ($hCPP_\nu$) model with the different choices of potential index ν have been studied. It is found that the masses of octet and decuplet baryons obtained from the $hCPP_\nu$ model are in good agreement with the experimental values around the potential index $\nu \approx 1.0$. Fig.(1) shows the behaviour of the predicted masses of the octet (1a) and decuplet (1b) baryons with the choices of the potential index ν from 0.5 to 1.5. The experimental masses of these baryons are shown with their error bar. The trend lines here show saturation of the masses beyond $\nu > 1.0$. The shaded regions in Fig.(1) show the neighbour hood region of ν at which the predicted masses are having minimum root mean square deviation with the experimental masses.

The computed magnetic moments of the octet and decuplet low lying baryons are compared with the known experimental results as well as with other model predictions in Table (1) and (2) respectively. Our results for the choice of $\nu \approx 0.7$ are found to be in agreement with the known experimental values as well as with other model predictions. The behavior of the predicted magnetic moments with potential index ν are shown in Fig.(2) of the octet (2a) and decuplet (2b) baryons. The same saturation trends beyond the potential index $\nu > 1.0$ are observed. The shaded region in Fig.(2a) corresponds to the region of ν ($0.6 < \nu < 0.7$) for which the predicted octet baryon magnetic moments show minimum root mean square deviation with the experiments. The predicted magnetic moments of the decuplet baryons in the same region of ν ($0.6 < \nu < 0.7$) are found to be closer to the existing experimental values of Δ and Ω baryons. Probably, it reflects the fact that $hCPP_\nu$ model potential adequately represents the three body quark-quark interactions in the baryonic sector.

Table 1: Mass of Octet Baryons ($J^P = \frac{1}{2}^+$)

$hCPP_\nu$	Baryon	Octet Mass(MeV)		Baryon	Octet Mass(MeV)	
		Our	Others		Our	Others
0.5	uud(p)	1065.68	939.00[5]	uds(Σ^0)	1344.67	1193.00[5]
0.7		967.41	938.27[43]		1239.94	1192.64[43]
1.0		931.08	866.00[44]		1203.29	1022.00[44]
1.5		924.24	938.27[1]		1195.98	1192.64[1]
0.5	ddu(n)	1067.24	939.00[5]	uds(Σ^-)	1345.46	1197.00[5]
0.7		971.74	939.57[43]		1243.71	1197.45[43]
1.0		935.77	866.00[44]		1205.99	1022.00[44]
1.5		929.04	939.56[1]		1199.06	1197.45[1]
0.5	uds(Λ^o)	1289.26	1116.00[5]	ssu(Ξ^o)	1420.19	1315.00[5]
0.7		1183.59	1115.68[43]		1331.65	1314.64[43]
1.0		1147.34	1022.00[44]		1297.09	1215.00[44]
1.5		1139.88	1115.65[1]		1291.43	1314.86[1]
0.5	uus(Σ^+)	1339.95	1189.00[5]	ssd(Ξ^-)	1428.97	1321.00[5]
0.7		1235.98	1189.39[43]		1340.44	1321.39[43]
1.0		1198.84	1022.00[44]		1306.55	1215.00[44]
1.5		1191.50	1189.37[1]		1299.61	1321.71[1]

Table 2: Mass of Decuplet Baryons ($J^P = \frac{3}{2}^+$)

$hCPP_\nu$	Baryon	Decuplet Mass(MeV)		Baryon	Decuplet Mass(MeV)	
		Our	Others		Our	Others
0.5	uuu(Δ^{++})	1361.68	1232.00[5]	uds(Σ^{*0})	1530.40	1384.00[5]
0.7		1264.17	1230.82[43]		1428.43	1384.18[43]
1.0		1228.63	1344.00[44]		1390.47	1447.00[44]
1.5		1221.21	1232.00[1]		1383.66	1383.70[1]
0.5	uud(Δ^+)	1358.30	1232.00[5]	dds(Σ^{*-})	1534.72	1387.00[5]
0.7		1260.78	1230.57[43]		1431.66	1387.18[43]
1.0		1223.74	1344.00[44]		1395.44	1447.00[44]
1.5		1216.33	1232.00[1]		1387.45	1387.20[1]
0.5	ddu(Δ^0)	1360.22	1232.00[5]	ssu(Ξ^{*0})	1640.49	1532.00[5]
0.7		1263.77	1231.87[43]		1549.05	1531.81[43]
1.0		1228.68	1344.00[44]		1516.19	1583.00[44]
1.5		1221.25	1232.00[1]		1508.03	1531.80[1]
0.5	ddd(Δ^-)	1356.79	1232.00[5]	ssd(Ξ^{*-})	1641.69	1535.00[5]
0.7		1260.32	1234.73[43]		1553.10	1534.95[43]
1.0		1223.65	1344.00[44]		1519.35	1583.00[44]
1.5		1217.80	1232.00[1]		1512.23	1535.00[1]
0.5	uus(Σ^{*+})	1534.60	1383.00[5]	sss(Ω^-)	1804.12	1672.00[5]
0.7		1430.54	1382.74[43]		1718.22	1672.45[43]
1.0		1392.93	1447.00[44]		1678.70	1701.00[44]
1.5		1386.16	1382.80[1]		1668.16	1672.45[1]

Table 3: Magnetic moments of octet baryons in μ_N

Various models	p	n	Λ^0	Σ^+	Σ^0	Σ^-	Ξ^0	Ξ^-
$hCPP_\nu$								
ν =1.5	3.07	-2.04	-0.65	2.64	0.84	-0.98	-1.50	-0.55
ν =1.0	3.04	-2.07	-0.64	2.63	0.83	-0.98	-1.49	-0.55
ν =0.7	2.93	-1.93	-0.62	2.54	0.81	-0.95	-1.46	-0.54
ν =0.5	2.66	-1.76	-0.57	2.35	0.74	-0.88	-1.37	-0.51
Expt.. [1]	2.79	-1.91	-0.61	2.46		-1.16	-1.25	-0.65
QCDSR [20]	2.82	-1.97	-0.56	2.31	0.69	-1.16	-1.15	-0.64
χCQM [23]	2.8	-2.11	-0.66	2.39	0.54	-1.32	-1.24	-0.50
χPT [11]	2.58	-2.10	-0.66	2.43	0.66	-1.10	-1.27	-0.95
Latt. [8]	2.79	-1.60	-0.50	2.37	0.65	-1.08	-1.17	-0.51
CDM [46]	2.79	-2.07	-0.71	2.47		-1.01	-1.52	-0.61
QM [47]	2.79	-1.91	-0.59	2.67	0.78	-1.10	-1.41	-0.47
QM + T [47]	2.79	-1.91	-0.61	2.39	0.63	-1.12	-1.24	-0.69
BAGCHI [5]	2.88	-1.91	-0.71	2.59	0.83	-0.92	-1.45	-0.62
Dai fit A [48]	2.84	-1.87		2.46		-1.06	-1.28	-0.61
Dai fit B [48]	2.80	-1.92		2.46		-1.23	-1.26	-0.63
SIMON [49]	2.54	-1.69	-0.69	2.48	0.80	-0.90	-1.49	-0.63
SU (3) BR. [50]	2.79	-1.97	-0.60	2.48	0.66	-1.16	-1.27	-0.65
PQM [45]	2.68	-1.99	-0.56	2.52		-1.17	-1.27	-0.59

Table 4: Magnetic moments of decuplet baryons in μ_N

Various models	Δ^{++}	Δ^+	Δ^0	Δ^-	Σ^{*+}	Σ^{*0}	Σ^{*-}	Ξ^{*0}	Ξ^{*-}	Ω^-
$hCPP_\nu$										
ν =1.5	4.69	2.37	0.05	-2.34	2.61	0.29	-2.42	0.53	-1.92	-1.68
ν =1.0	4.66	2.35	0.05	-2.33	2.60	0.28	-2.40	0.53	-1.91	-1.67
ν =0.7	4.52	2.29	0.05	-2.25	2.53	0.27	-2.32	0.52	-1.87	-1.63
ν =0.5	4.19	2.12	0.05	-2.08	2.35	0.26	-2.15	0.49	-1.77	-1.56
Expt.. [1, 2, 3]	4.5 ± 0.95 3.5 – 7.5	$2.70^{+1.0}_{-1.3}$	≈ 0.00							
LCQCD [6]	4.49	2.20	0.00	-2.20	2.70	0.20	-2.28	0.40	-2.00	-1.56
QCDSR [7]	4.39	2.19	0.00	-2.19	2.13	0.32	-1.66	-0.69	-1.51	-1.49
Latt. [8]	4.91	2.46	0.00	-2.46	2.55	0.27	-2.02	0.46	-1.66	-1.40
χPT [11]	6.04	2.84	-0.36	-3.56	3.07	0.00	-3.07	0.36	-2.56	-2.02
χPT [12]	4.00	2.10	-0.17	-2.25	2.00	-0.07	-2.20	0.10	-2.00	Input
RQM [16]	4.76	2.38	0.00	-2.38	1.82	-0.27	-2.36	-0.60	-2.41	-2.48
NRQM [18]	5.56	2.73	-0.09	-2.92	3.09	0.27	-2.56	0.63	-2.20	-1.81
χQSM [21]	4.73	2.19	-0.35	-2.90	2.52	-0.08	-2.69	0.19	-2.48	-2.27
χCQSM [23]	4.51	2.00	-0.51	-3.02	2.69	0.02	-2.64	0.54	-1.84	-1.71
χB [24]	3.59	0.75	-2.09	-1.93	2.35	-0.79	-3.87	0.58	-2.81	-1.75
EMS [51]	4.56	2.28	0.00	-2.28	2.56	0.23	-2.10	0.48	-1.90	-1.67
QCDSR [52]	6.34	3.17	0.00	-3.17						

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