Radiative M1 Decays of Heavy Flavor Baryons in Effective Mass Scheme

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Outline

Introduction

- Despite the fact that the Standard Model is a well established framework to study interactions of fundamental particles, significant discrepancies can be seen between theoretical predictions and experimental results. However, within the past few decades, several theoretical approaches have been put forth to diminish the inconsistency between theory and experiments.
- In the present work, we have calculated magnetic and transition moments, and M1 decay widths of ground-state singly, doubly, and triply heavy baryons. Also, we have given the estimates for the magnetic moments in an improved manner by determining hyperfine (one gluon exchange) interaction terms for $s-$, $c-$, and $b-$flavors from precise experimental values of baryon masses within the same flavor sector.
- Following the EMS [1, 2, 3], we have calculated the constituent and effective masses of quarks inside a baryon for both $J^P = \frac{1}{2}^+$ and $J^P = \frac{3}{2}^+$ baryons.

Theoretical frame work (EMS)

- In the EMS, the baryon mass can be written as the sum of the constituent quark masses and the spin-dependent hyperfine interaction among them [1, 2, 3],

$$M_{\mathcal{B}} = \sum_i m_i^{\xi} = \sum_i m_i + \sum_{i<j} b_{ij} s_i . s_j, \tag{1}$$

where, m_i^{ξ} represents the effective mass of the quark inside the baryon; s_i and s_j denote the spin operators of the i^{th} and j^{th} quark, respectively.

- The b_{ij} for baryons $\mathcal{B}(qqq)$, is given by

$$b_{ij} = \frac{16\pi\alpha_s}{9m_i m_j} < \psi_0|\delta^3(\vec{r})|\psi_0 >, \tag{2}$$

where, ψ_0 is the baryon wave function at the origin.

Theoretical frame work (continues)

- For (112)- type $J^P = \frac{1}{2}^+$ baryons, we can write

$$\begin{aligned} m_1^{\xi} = m_2^{\xi} &= m + \alpha b_{12} + \beta b_{13}, \\ m_3^{\xi} &= m_3 + 2\beta b_{13}, \end{aligned} \tag{3}$$

where, $m_1 = m_2 = m$ and $b_{13} = b_{23}$. The α and β parameters are to be determined as follows:

$$M_{\mathcal{B}_{\frac{1}{2}^+}} = 2m + m_3 + \frac{b_{12}}{4} - b_{13}, \tag{4}$$

for

$$s_1.s_2 = \frac{1}{4}, s_1.s_3 = s_2.s_3 = -\frac{1}{2}, \tag{5}$$

thus giving

$$\alpha = \frac{1}{8} \text{ and } \beta = -\frac{1}{4}. \tag{6}$$

Theoretical frame work (continues)

- Therefore, equation (1) may be generalized for $J^P = \frac{1}{2}^+$ baryons as

$$M_{\mathcal{B}_{\frac{1}{2}^+}} = m_1 + m_2 + m_3 + \frac{b_{12}}{4} - \frac{b_{23}}{2} - \frac{b_{13}}{2}. \tag{7}$$

- By using equation (3), we will obtain more general expressions for effective masses of the quarks inside the baryon, as follows:
  1. For (112)-type $J^P = \frac{1}{2}^+$ baryons with quarks 1 and 2 being identical,

$$m_1^{\xi} = m_2^{\xi} = m + \frac{b_{12}}{8} - \frac{b_{13}}{4}, \tag{8}$$

and

$$m_3^{\xi} = m_3 - \frac{b_{13}}{2} \text{ for } 1 = 2 \neq 3. \tag{9}$$

Theoretical frame work (continues)

2. The baryonic states with three different quarks flavor (123) can have both anti-symmetric $\Lambda_{[12]3}$-type and symmetric $\Sigma_{\{12\}3}$-type flavor configuration under the exchange of quarks 1 and 2. (a) For (123) Λ-type, $J^P = \frac{1}{2}^+$ baryons,

$$m_1^{\xi} = m_1 - \frac{3b_{12}}{8}, \quad m_2^{\xi} = m_2 - \frac{3b_{21}}{8}, \tag{10}$$

and

$$m_3^{\xi} = m_3 \text{ for } 1 \neq 2 \neq 3. \tag{11}$$

(b) For (123) Σ-type, $J^P = \frac{1}{2}^+$ baryons,

$$m_1^{\xi} = m_1 + \frac{b_{12}}{8} - \frac{b_{13}}{4}, \quad m_2^{\xi} = m_2 + \frac{b_{12}}{8} - \frac{b_{23}}{4}, \tag{12}$$

and

$$m_3^{\xi} = m_3 - \frac{b_{23}}{4} - \frac{b_{13}}{4} \text{ for } 1 \neq 2 \neq 3. \tag{13}$$

Theoretical frame work (continues)

- Following the similar procedure described for $J^P = \frac{1}{2}^+$ baryons, the generalized mass formula for different flavor configuration of $J^P = \frac{3}{2}^+$ baryons is given by

$$M_{\mathcal{B}_{\frac{3}{2}^+}} = m_1 + m_2 + m_3 + \frac{b_{12}}{4} + \frac{b_{23}}{4} + \frac{b_{13}}{4}, \quad \text{for } \alpha = \beta = \frac{1}{8}. \tag{14}$$

Throughout the above discussions 1, 2, 3 represents u, d, s, c, and b quarks.
1. For (112)-type $J^P = \frac{3}{2}^+$ baryons,

$$m_1^{\xi} = m_2^{\xi} = m + \frac{b_{12}}{8} + \frac{b_{13}}{8}, \tag{15}$$

and

$$m_3^{\xi} = m_3 + \frac{b_{13}}{4} \text{ for } 1 = 2 \neq 3. \tag{16}$$

Theoretical frame work (continues)

2. For (123)-type $J^P = \frac{3}{2}^+$ baryons,

$$
\begin{aligned}
m_1^\xi &= m_1 + \frac{b_{12}}{8} + \frac{b_{13}}{8}, \\
m_2^\xi &= m_2 + \frac{b_{23}}{8} + \frac{b_{12}}{8},
\end{aligned} \tag{17}
$$

and

$$
m_3^\xi = m_3 + \frac{b_{13}}{8} + \frac{b_{23}}{8}. \tag{18}
$$

3. For (111)-type $J^P = \frac{3}{2}^+$ baryons,

$$
m_1^\xi = m_2^\xi = m_3^\xi = m + \frac{b_{12}}{4}, \tag{19}
$$

and

$$
b_{12} = b_{23} = b_{13}. \tag{20}
$$

Theoretical frame work (continues)

- The values of constituent quark masses and hyperfine interaction terms b_{ij} are obtained from the experimentally observed baryon masses [4]. In order to obtain the effective quark masses, especially in the charm and bottom sector, we have calculated the interaction contribution of single gluon exchange term from the corresponding flavor sector. We proceed to obtain,

$$m_u = m_d = 362\ MeV, m_s = 538\ MeV, \\ b_{uu} = b_{ud} = b_{dd} = 195\ MeV. \tag{21}$$

from N, Δ, and Λ up to strange sector.
In the charm sector, from Ω_c and $\Xi_c^{(*)}$, we obtain:

$$m_c = 1646\ MeV, b_{us} = b_{ds} = 153\ MeV,$$

$b_{ss} = 81\ MeV$, (22)$\Sigma_c^{(*)}$ will gives

$$b_{uc} = b_{dc} = 43\ MeV, \tag{23}$$

and $\Omega_c^{(*)}$, and Ξ_{cc}^{++} yields

$$b_{sc} = 47\ MeV, \tag{24}$$

Theoretical frame work (continues)

and

$$b_{cc} = 40\ MeV. \tag{25}$$

In the bottom sector, Λ_b, $\Sigma_b^{(*)}$, and $\Xi_b^{(*)}$ leads to

$$m_b = 5043\ MeV, b_{ub} = b_{db} = 13\ MeV, b_{sb} = 17\ MeV. \tag{26}$$

For the first time we have estimated b_{cb} and b_{bb} from the hyperfine interaction terms b_{sc} and b_{sb} that are obtained from the experimentally known masses. We use the symmetry relations [1, 2, 3] to get,

$$b_{cb} = \left(\frac{m_s}{m_b}\right) b_{sc} = 5.0\ MeV, \text{ and } b_{cb} = \left(\frac{m_s}{m_c}\right) b_{sb} = 5.4\ MeV, \tag{27}$$

since both the values are roughly same, we use

$$b_{cb} \cong 5\ MeV. \tag{28}$$

Furthermore, we get

$$b_{bb} = \left(\frac{m_s m_c}{m_b m_b}\right) b_{sc} = 1.6\ MeV, \text{ and } b_{bb} = \left(\frac{m_s m_b}{m_b m_b}\right) b_{sb} = 1.8\ MeV. \tag{29}$$

which is approximated to

$$b_{bb} \cong 2\ MeV. \tag{30}$$

Theoretical frame work (continues)

- Effective quark masses for $J^P = \frac{1}{2}^+$ baryons
  1. For singly heavy baryons,

$$m_u^{\Lambda c} = m_d^{\Lambda c} = 289\ MeV, m_c^{\Lambda c} = 1646\ MeV;$$
$$m_u^{\Sigma c} = m_d^{\Sigma c} = 376\ MeV, m_c^{\Sigma c} = 1625\ MeV;$$
$$m_u^{\Xi' c} = m_d^{\Xi' c} = 370\ MeV, m_s^{\Xi' c} = 545\ MeV, m_c^{\Xi' c} = 1624\ MeV;$$
$$m_u^{\Xi c} = m_d^{\Xi c} = 305\ MeV, m_s^{\Xi c} = 481\ MeV, m_c^{\Xi c} = 1646\ MeV;$$
$$m_s^{\Omega c} = 536\ MeV, m_c^{\Omega c} = 1622\ MeV;$$
$$m_u^{\Lambda b} = m_d^{\Lambda b} = 289\ MeV, m_b^{\Lambda b} = 5043\ MeV;$$
$$m_u^{\Xi b} = m_d^{\Xi b} = 305\ MeV, m_s^{\Xi b} = 481\ MeV, m_b^{\Xi b} = 5043\ MeV;$$
$$m_s^{\Omega b} = 544\ MeV, m_b^{\Omega b} = 5035\ MeV;$$
$$m_u^{\Sigma b} = m_d^{\Sigma b} = 383\ MeV, m_b^{\Sigma b} = 5036\ MeV;$$
$$m_u^{\Xi' b} = m_d^{\Xi' b} = 378\ MeV, m_s^{\Xi' b} = 553\ MeV, m_b^{\Xi' b} = 5036\ MeV.$$

Theoretical frame work (continues)

- Effective quark masses for $J^P = \frac{3}{2}^+$ baryons
  1. For singly heavy baryons,

$$m_u^{\Sigma_c^*} = m_d^{\Sigma_c^*} = 392\ MeV, m_c^{\Sigma_c^*} = 1657\ MeV;$$

$$m_u^{\Xi_c^*} = m_d^{\Xi_c^*} = 386\ MeV, m_s^{\Xi_c^*} = 563\ MeV, m_c^{\Xi_c^*} = 1657\ MeV;$$

$$m_s^{\Omega_c^*} = 554\ MeV, m_c^{\Omega_c^*} = 1658\ MeV;$$

$$m_u^{\Sigma_b^*} = m_d^{\Sigma_b^*} = 388\ MeV, m_b^{\Sigma_b^*} = 5046\ MeV;$$

$$m_u^{\Xi_b^*} = m_d^{\Xi_b^*} = 383\ MeV, m_s^{\Xi_b^*} = 559\ MeV, m_b^{\Xi_b^*} = 5047\ MeV;$$

$$m_s^{\Omega_b^*} = 550\ MeV, m_b^{\Omega_b^*} = 5047\ MeV.$$

Magnetic Moments of Heavy Flavor Baryons

- Magnetic Moments of ($J^P = \frac{1}{2}^+$) and ($J^P = \frac{3}{2}^+$) Baryons

$$\begin{aligned} \mu(\mathcal{B}) &= \frac{1}{3}(4\mu_1^\xi - \mu_2^\xi), \\ \mu(\mathcal{B}) &= \mu_3^\xi, \\ \mu(\mathcal{B}') &= \frac{1}{3}(2\mu_1^\xi + 2\mu_2^\xi - \mu_3^\xi), \\ \mu(\mathcal{B}^*) &= \mu_1^\xi + \mu_2^\xi + \mu_3^\xi. \end{aligned} \tag{31}$$

where, $\mu_i^\xi = \frac{e_i}{2m_i^\xi}$ denote the effective magnetic moments of first, second and third quarks, respectively. We adopt the convention that $[q_1 q_2]$ denotes anti-symmetric (S = 0) and $\{q_1 q_2\}$ denote symmetric (S = 1) combinations of quark flavor indices (with respect to the interchange of q_1 and q_2):

$$\begin{aligned} |\mathcal{B}\rangle &= \left| [q_1 q_2]^{S=0} q_3, J = \frac{1}{2} \right\rangle \\ |\mathcal{B}'\rangle &= \left| \{q_1 q_2\}^{S=1} q_3, J = \frac{1}{2} \right\rangle \\ |\mathcal{B}^*\rangle &= \left| \{q_1 q_2\}^{S=1} q_3, J = \frac{3}{2} \right\rangle. \end{aligned} \tag{32}$$

Transition Moments of Heavy Flavor Baryons

- Transition Moments Relations

$$\mu_{\frac{1}{2}'^+ \to \frac{1}{2}^+} = \sqrt{\frac{1}{3}}\left[\mu^{\xi}(2) - \mu^{\xi}(1)\right],$$
$$\mu_{\frac{3}{2}^+ \to \frac{1}{2}^+} = \sqrt{\frac{2}{3}}\left[\mu^{\xi}(1) - \mu^{\xi}(2)\right], \tag{33}$$
$$\mu_{\frac{3}{2}^+ \to \frac{1}{2}'^+} = \frac{\sqrt{2}}{3}\left[\mu^{\xi}(1) + \mu^{\xi}(2) - 2\mu^{\xi}(3)\right].$$

To evaluate $\mu_{\frac{1}{2}'^+ \to \frac{1}{2}^+}$ and $\mu_{\frac{3}{2}^+ \to \frac{1}{2}^+}$ transition moments, we take the geometric mean of effective quark masses of the constituent quarks of initial and final state baryons.

$$m_i^{\xi}(\mathcal{B}_J'^{(*)} \to \mathcal{B}_J) = \sqrt{m_i^{\xi}(\mathcal{B}_J'^{(*)})m_i^{\xi}(\mathcal{B}_J)}, \tag{34}$$

where, symbols have their usual meaning.

Transition Moments of Heavy Flavor Baryons

- Using the Eqs. (8) - (13) and (15) - (20), we calculate the transition masses of baryons as follows:

$$m_u^{\Lambda_c} = m_d^{\Lambda_c} = 336\ MeV, m_c^{\Lambda_c} = 1651\ MeV;$$

$$m_u^{\Xi_c} = m_d^{\Xi_c} = 343\ MeV, m_s^{\Xi_c} = 520\ MeV, m_c^{\Xi_c} = 1652\ MeV;$$

$$m_u^{\Sigma_c} = m_d^{\Sigma_c} = 384\ MeV, m_c^{\Sigma_c} = 1640\ MeV;$$

$$m_u^{\Xi'_c} = m_d^{\Xi'_c} = 378\ MeV, m_s^{\Xi'_c} = 554\ MeV, m_c^{\Xi'_c} = 1640\ MeV.$$

$$m_s^{\Omega_c} = 545\ MeV, m_c^{\Omega_c} = 1640\ MeV;$$

Radiative Decay Widths of Heavy Flavor Baryons

- We will continue our presentation with the analysis for M1 partial widths of the ground state heavy baryons. We ignore the transition of type E2 which is expected to be much smaller in magnitude [5, 6] when compared to M1. The radiative decay widths of the decay type $\mathcal{B}_J'^{(*)} \to \mathcal{B}_J\gamma$ (Ref. [7, 8]) is given by

$$\Gamma(\mathcal{B}_J'^{(*)} \to \mathcal{B}_J\gamma) = \frac{\alpha\omega^3}{m_p^2}\frac{2}{(2J+1)}|\mu(\mathcal{B}_J'^{(*)} \to \mathcal{B}_J)|^2, \tag{35}$$

where,

$$\omega = \frac{M^2_{\mathcal{B}'^{(*)}} - M^2_{\mathcal{B}}}{2M_{\mathcal{B}'^{(*)}}}, \tag{36}$$

is the photon momentum in the center-of-mass system of the initial baryon states. Here, $\mu(\mathcal{B}_J'^{(*)} \to \mathcal{B}_J)$ is the transition magnetic moment (in μ_N), J is the spin quantum number for parent state, and $M_{\mathcal{B}'^{(*)}}$ and $M_{\mathcal{B}}$ are the masses of initial and final baryon state, respectively.

Numerical Results

Table: I. Magnetic moments (in nuclear magneton, μ_N) of $J^P = 1/2^+$ charm baryons.

Baryons	EMS	[8]	[10]	[14]	[12]	[15]	[16]	[17]
Λ_c^+	0.380	0.335	-	-	0.421	-0.232	-	-
Σ_c^{++}	2.091	2.280	2.15 ± 0.1	2.027	1.831	1.604	-	-
Σ_c^+	0.427	0.487	0.46 ± 0.03	-	0.380	0.100	-	-
Σ_c^0	-1.238	-1.310	-1.24 ± 0.05	-1.117	-1.091	-1.403	-	-
Ξ_c^+	0.380	0.142	-	-	-	0.233	-	-
Ξ_c^0	0.380	0.346	-	-	-	0.193	-	-
$\Xi_c'^+$	0.615	0.825	0.60 ± 0.02	-	0.523	0.559	-	-
$\Xi_c'^0$	-1.074	-1.130	-1.05 ± 0.04	-	-1.012	-1.077	-	-
Ω_c^0	-0.906	-0.950	-0.85 ± 0.05	-0.639	-1.179	-0.748	-	-
Ξ_{cc}^{++}	-0.104	-0.110	-	-	-	-	-	-0.23 ± 0.05
Ξ_{cc}^+	0.815	0.719	-	0.425	-	-	0.392	0.43 ± 0.09
Ω_{cc}^+	0.711	0.645	-	0.413	-	-	0.397	0.39 ± 0.09

Numerical Results

Table: II. Magnetic moments (in μ_N) of $J^P = 3/2^+$ charm baryons.

Baryons	EMS	[8]	[9]	[10]	[11]	[12]	[13]
Σ_c^{*++}	3.570	3.980	2.410	3.22 ± 0.15	4.81 ± 1.22	3.232	-
Σ_c^{*+}	1.176	1.250	0.670	0.68 ± 0.04	2.00 ± 0.46	1.136	-
Σ_c^{*0}	-1.219	-1.490	-1.070	-1.86 ± 0.07	-0.81 ± 0.20	-1.044	-
Ξ_c^{*+}	1.440	1.470	0.810	0.90 ± 0.04	1.68 ± 0.42	1.333	-
Ξ_c^{*0}	-0.987	-1.200	-0.900	-1.57 ± 0.06	-0.68 ± 0.18	-0.837	-
Ω_c^{*0}	-0.752	-0.936	-0.700	-1.28 ± 0.08	-0.62 ± 0.18	-1.129	-
Ξ_{cc}^{*++}	2.433	2.350	-	-	-	-	2.940
Ξ_{cc}^{*+}	-0.084	-0.178	-	-	-	-	-0.670
Ω_{cc}^{*+}	0.186	0.048	-	-	-	-	-0.520
Ω_{ccc}^{*++}	1.133	0.989	-	-	-	-	-

Numerical Results

Table: III. Magnetic $\mu_{\frac{3}{2}^+\rightarrow\frac{1}{2}^+}$ transition moments (in μ_N) of charm baryons.

Transition	EMS	[18]	[8]	[19]	[6]	[20]*	[12]	[23]
$\Sigma_c^{*+} \rightarrow \Lambda_c^+$	2.277	2.400	2.070	2.000	-2.18 ± 0.08	1.48 ± 0.55	1.758	-
$\Sigma_c^{*++} \rightarrow \Sigma_c^{++}$	1.177	-1.370	1.340	1.070	1.52 ± 0.07	1.06 ± 0.38	0.988	-
$\Sigma_c^{*+} \rightarrow \Sigma_c^+$	0.025	-0.003	0.102	0.190	0.33 ± 0.02	0.45 ± 0.11	0.009	-
$\Sigma_c^{*0} \rightarrow \Sigma_c^0$	-1.128	1.480	-1.140	-0.690	-0.87 ± 0.03	0.19 ± 0.08	1.013	-
$\Xi_c^{*+} \rightarrow \Xi_c^+$	1.979	2.080	1.860	1.050	1.69 ± 0.08	1.47 ± 0.66	0.985	-
$\Xi_c^{*0} \rightarrow \Xi_c^0$	-0.253	-0.500	-0.249	-0.310	-0.29 ± 0.04	0.16 ± 0.075	0.253	-
$\Xi_c^{*+} \rightarrow \Xi_c^{'+}$	0.154	-0.230	0.066	0.230	0.43 ± 0.02	-	-	-
$\Xi_c^{*0} \rightarrow \Xi_c^{'0}$	-1.015	1.240	-0.994	-0.590	-0.74 ± 0.03	-	-	-
$\Omega_c^{*0} \rightarrow \Omega_c^0$	-0.900	0.960	-0.892	-0.490	-0.60 ± 0.04	-	0.872	-
$\Xi_{cc}^{*++} \rightarrow \Xi_{cc}^{++}$	-1.298	1.330	-1.210	-	-	-	-	-2.350
$\Xi_{cc}^{*+} \rightarrow \Xi_{cc}^+$	1.185	-1.410	1.070	-	-	-	-	1.550
$\Omega_{cc}^{*+} \rightarrow \Omega_{cc}^+$	0.912	-0.890	0.869	-	-	-	-	1.540

*T. M. Aliev, K. Azizi and A. Ozpineci have given their results in natural magneton ($e\hbar/2cM_{\mathcal{B}}$), however, to convert to nuclear magneton we multiply the entire magnetic moments with $2m_N/(M_{\mathcal{B}_{3/2^+}} + M_{\mathcal{B}_{1/2^+}})$.

Numerical Results

Table: IV. Photon momenta, ω of charm and bottom baryons.

Transition	ω (in MeV)	**[8]**	**Transition**	ω (in MeV)	**[8]**
$\Sigma_c^+ \to \Lambda_c^+$	161	160	$\Sigma_b^0 \to \Lambda_b^0$	193	190
$\Xi_c'^0 \to \Xi_c^0$	106	105	$\Xi_b'^0 \to \Xi_b^0$	141	135
$\Xi_c'^+ \to \Xi_c^+$	108	106	$\Xi_b'^- \to \Xi_b^-$	136	138
$\Sigma_c^{*+} \to \Lambda_c^+$	220	220	$\Sigma_b^{*0} \to \Lambda_b^0$	209	210
$\Sigma_c^{*0} \to \Sigma_c^0$	64	64	$\Sigma_b^{*0} \to \Sigma_b^0$	17	20
$\Sigma_c^{*+} \to \Sigma_c^+$	64	64	$\Sigma_b^{*-} \to \Sigma_b^-$	19	20
$\Sigma_c^{*++} \to \Sigma_c^{++}$	64	64	$\Sigma_b^{*+} \to \Sigma_b^+$	20	20
$\Xi_c^{*0} \to \Xi_c^0$	170	169	$\Xi_b^{*0} \to \Xi_b^0$	158	155
$\Xi_c^{*+} \to \Xi_c^+$	172	172	$\Xi_b^{*-} \to \Xi_b^-$	156	158
$\Xi_c^{*0} \to \Xi_c'^0$	66	67	$\Xi_b^{*0} \to \Xi_b'^0$	17	20
$\Xi_c^{*+} \to \Xi_c'^+$	66	69	$\Xi_b^{*-} \to \Xi_b'^-$	20	20
$\Omega_c^{*0} \to \Omega_c^0$	70	70	$\Omega_b^{*-} \to \Omega_b^-$	39	20

Numerical Results

Table: V. The radiative decay widths (in KeV) of charm baryons.

Transition	EMS	[24]	[8]	[19]	[6]†	[20, 21, 22]	[25]	[26]	[12]
$\Sigma_c^+ \to \Lambda_c^+\gamma$	93.22	46.10	74.10	65.60	81.05	50.00	80.60	97.98	66.66
$\Xi_c^{\prime 0} \to \Xi_c^0\gamma$	0.338	0.002	0.185	0.460	0.432	0.270	0000	-	-
$\Xi_c^{\prime +} \to \Xi_c^+\gamma$	21.36	10.20	18.60	5.430	14.78	8.500	42.30	-	-
$\Sigma_c^{*+} \to \Lambda_c^+\gamma$	230.3	126.0	190.0	161.6	211.1	130.0	373.0	244.4	135.3
$\Sigma_c^{*++} \to \Sigma_c^{++}\gamma$	1.480	0.826	1.960	1.200	2.468	2.650	3.940	1.980	2.060
$\Sigma_c^{*0} \to \Sigma_c^0\gamma$	1.376	1.080	1.410	0.490	0.818	0.080	3.430	1.440	2.162
$\Sigma_c^{*+} \to \Sigma_c^+\gamma$	0.001	0.004	0.011	0.040	0.174	0.400	0.040	0.011	4×10^{-5}
$\Xi_c^{*0} \to \Xi_c^0\gamma$	1.299	0.908	0.745	1.840	1.707	0.660	0000	1.150	0.811
$\Xi_c^{*+} \to \Xi_c^+\gamma$	82.18	44.30	81.60	21.60	59.93	52.00	139.0	99.94	15.69
$\Xi_c^{*0} \to \Xi_c^{\prime 0}\gamma$	1.247	1.030	1.330	0.420	0.663	2.142	3.030	-	-
$\Xi_c^{*+} \to \Xi_c^{\prime +}\gamma$	0.028	0.011	0.063	0.070	0.218	0.274	0.004	-	-
$\Omega_c^{*0} \to \Omega_c^0\gamma$	1.143	1.070	1.130	0.320	0.508	0.932	0.890	0.820	0.464
$\Xi_{cc}^{*++} \to \Xi_{cc}^{++}\gamma$	2.427	1.430	2.790	-	-	-	-	-	-
$\Xi_{cc}^{*+} \to \Xi_{cc}^+\gamma$	2.026	2.080	2.170	-	-	-	-	-	-
$\Omega_{cc}^{*+} \to \Omega_{cc}^+\gamma$	1.978	0.949	1.600	-	-	-	-	-	-

Summary and Conclusion

- In the present work, we have primarily focused on the prediction of magnetic properties of heavy flavor baryons in the framework of EMS. The EMS takes into account the modification based on hyperfine interaction between constituent quarks via one gluon exchange inside the baryon. Another unique feature of EMS is that it is parameter independent and, in addition, we have also incorporated symmetry breaking (through masses), which is a desirable feature for consistent predictions of baryon properties. We have calculated the magnetic and transition moments involving low-lying heavy baryons containing up to three heavy quarks, and consequently, have predicted M1 radiative decay widths for $\frac{1}{2}' \rightarrow \frac{1}{2}$ and $\frac{3}{2} \rightarrow \frac{1}{2}$ baryon states. Also, we have compared our results with existing predictions from other theoretical models. In order to make robust predictions, we have utilized precisely measured experimental values of baryon masses, and have used LQCD estimates in the case of unobserved baryons.
- Following the current approach, we have accomplished two improvements. Firstly, symmetry breaking (through masses and interaction terms) is partially incorporated, and secondly, a more reliable calculation of effective masses has been achieved. In addition, we have tried to limit the uncertainties in photon momenta by mostly relying on experimental information. In the light of preceding arguments, it is therefore expected that our results would provide reasonably accurate predictions of magnetic (transition) moments and M1 radiative decay widths.

Bibliography

- S. Kumar, R. Dhir and R. C. Verma, J. Phys. G **31**, no.2, 141-147 (2005) doi:10.1088/0954-3899/31/2/006
- R. Dhir and R. Verma, Eur. Phys. J. A **42**, 243-249 (2009) doi:10.1140/epja/i2009-10872-8 [arXiv:0904.2124 [hep-ph]].
- R. Dhir, C. S. Kim and R. C. Verma, Phys. Rev. D **88**, 094002 (2013) doi:10.1103/PhysRevD.88.094002 [arXiv:1309.4057 [hep-ph]].
- P. A. Zyla *et al.* [Particle Data Group], PTEP **2020**, no.8, 083C01 (2020) doi:10.1093/ptep/ptaa104
- H. Bahtiyar, K. U. Can, G. Erkol, M. Oka and T. T. Takahashi, Phys. Rev. D **98**, no.11, 114505 (2018) doi:10.1103/PhysRevD.98.114505 [arXiv:1807.06795 [hep-lat]].
- G. S. Yang and H. C. Kim, Phys. Lett. B **801**, 135142 (2020) doi:10.1016/j.physletb.2019.135142 [arXiv:1909.03156 [hep-ph]].
- J. Dey, V. Shevchenko, P. Volkovitsky and M. Dey, Phys. Lett. B **337**, 185-188 (1994) doi:10.1016/0370-2693(94)91466-4
- V. Simonis, arXiv:1803.01809 [hep-ph].
- L. Meng, G. J. Wang, C. Z. Leng, Z. W. Liu and S. L. Zhu, Phys. Rev. D **98**, no. 9,