Isospin splitting and quark charge screening effects on M1 decay widths of charm baryons

Thejus Mary S.
Department of Physics and Nanotechnology,
SRM Institute of Science and Technology, Chennai, India.

Motivation

The electromagnetic properties and radiative transitions of heavy flavor baryons improves our comprehension of the heavy-quark dynamics. Recent experiments by BABAR and Belle collaborations have observed the following radiative decay processes, $\Omega_c^{*0} \to \Omega_c^0\gamma$, $\Xi_c'^{+} \to \Xi_c^{+}\gamma$ and $\Xi_c'^{0} \to \Xi_c^{0}\gamma$. The above transitions stand as the suitable candidates for understanding the isospin symmetry breaking, as they are the different charge states in the same isoplet.

Primary Objective

To evaluate the effect of isospin breaking and quark charge screening in transition magnetic moments and radiative M1 decay width results of $\frac{1}{2}'^{+} \to \frac{1}{2}^{+}$ and $\frac{3}{2}^{+} \to \frac{1}{2}^{(\prime)+}$ charm baryon transitions.

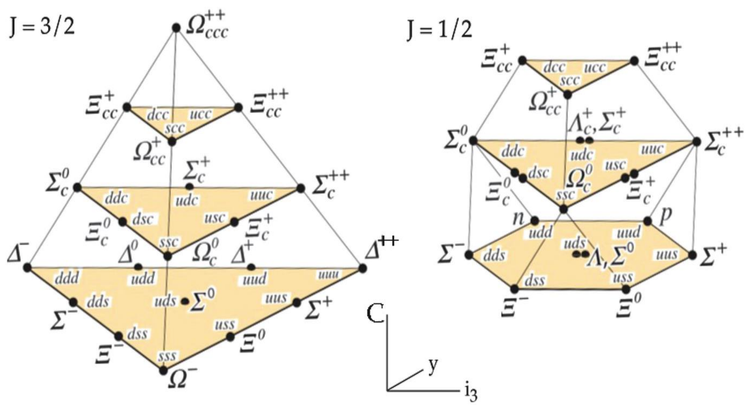
Effective Mass Scheme

The quark mass gets modified due to its one-gluon exchange interaction with the spectator quarks inside a baryon[1]. Thus, the EMS expresses the baryon mass as the sum of the constituent quark masses and the spin-dependent strong hyperfine interaction terms,

$$M_B = \sum_i m_i^{\varepsilon} = \sum_i m_i + \sum_{i<j} b_{ij} s_i . s_j$$

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

Isospin Breaking



In our work, we incorporate the isospin symmetry breaking through two different sources :

- ❑ Constituent quark masses (m_i)
- ❑ Strong hyperfine interaction terms (b_{ij})

Effective Quark Charge

Similar to the quark mass, the charge of a quark inside a baryon also varies because of the neighboring quarks. Thus, when being probed by a soft photon, the spectator quarks may shield the charge of the quark under the probe, leading to the modification of the quark charge

$$e_i^{\varepsilon} = e_i + \alpha_{ij} e_j + \alpha_{ik} e_k$$

By choosing $\alpha_{ij} = \alpha_{ji}$ and invoking the isospin symmetry [*SU(2)*] as follows,

$$\boldsymbol{\alpha_{uu} = \alpha_{ud} = \alpha_{dd} = x = 0.103},$$

while, in the strange sector [*SU(3)*],

$$\boldsymbol{\alpha_{us} = \alpha_{ds} = \alpha_{ss} = y = 0.133},$$

and, for the charm sector [*SU(4)*],

$$\boldsymbol{\alpha_{uc} = \alpha_{dc} = \alpha_{sc} = \alpha_{cc} = z = 0.021}.$$

Constituent quark masses (m_i)	Hyperfine interaction terms (b_{ij})
m_u = 360.534 m_d = 363.491	b_{uu} = 200.536 b_{ud} = 197.752 b_{dd} = 193.884
m_s = 539.972	b_{us} = 143.129 b_{ds} = 139.236 b_{ss} = 70.045
m_c = 1644.878	b_{uc} = 42.067 b_{dc} = 42.814 b_{sc} = 47.133 b_{cc} = 53.508

Magnetic Moments

Magnetic moments of baryons are obtained by sandwiching the magnetic moment operator, $\boldsymbol{\mu}$ between appropriate baryon wavefunctions,

$$\mu_B = < \psi|\boldsymbol{\mu}|\psi >$$

$$\boldsymbol{\mu} = \sum_i \frac{e_i^{\varepsilon}}{2m_i^{\varepsilon}} \boldsymbol{\sigma_i}$$

Transition Moments

The general expressions for transition magnetic moments of $\frac{1}{2}'^{+} \to \frac{1}{2}^{+}$, $\frac{3}{2}^{+} \to \frac{1}{2}^{+}$ and $\frac{3}{2}^{+} \to \frac{1}{2}'^{+}$ transitions are given by,

$$\mu_{B'\to B} = \frac{1}{\sqrt{3}}[\mu_j^{\varepsilon} - \mu_i^{\varepsilon}]$$

$$\mu_{B^*\to B} = \sqrt{\frac{2}{3}}\,[\mu_i^{\varepsilon} - \mu_j^{\varepsilon}]$$

$$\mu_{B^*\to B'} = \frac{\sqrt{2}}{3}\,[\mu_i^{\varepsilon} + \mu_j^{\varepsilon} - 2\mu_k^{\varepsilon}]$$

To evaluate the transition magnetic moments, we take the geometric mean of the effective masses of the constituent quarks of initial and final baryon states.

$$m_i^{B'^{(*)}\to B^{(\prime)}} = \sqrt{m_i^{\varepsilon}(B'^{(*)}) m_i^{\varepsilon}(B^{(\prime)})}$$

Radiative Decay Widths

$$\Gamma_{B'^{(*)}\to B^{(\prime)}\gamma} = \frac{\alpha\omega^3}{M_p^2}\frac{2}{(2J+1)}|\mu_{B'^{(*)}\to B^{(\prime)}}|^2$$

Photon momentum, $\omega = \frac{M^2_{B'^{(*)}} - M^2_{B^{(\prime)}}}{2M_{B'^{(*)}}}$

Results

Transition magnetic moments (in μ_N)		
Transitions	*EMS*	*SQCS*
$\Sigma_c^+ \to \Lambda_c^+$	-1.65	-1.48
$\Xi_c'^0 \to \Xi_c^0$	0.18	0.20
$\Sigma_c^{*+} \to \Sigma_c^+$	0.03	0.10
$\Xi_c^{*+} \to \Xi_c'^+$	0.16	0.20
$\Omega_c^{*0} \to \Omega_c^0$	-0.90	-0.94
$\Xi_{cc}^{*+} \to \Xi_{cc}^+$	1.18	1.12
$\Omega_{cc}^{*+} \to \Omega_{cc}^+$	0.91	0.87

Radiative decay widths (in keV)		
Transitions	*EMS*	*SQCS*
$\Sigma_c^+ \to \Lambda_c^+\gamma$	93.70	75.46
$\Xi_c'^0 \to \Xi_c^0\gamma$	0.327	0.389
$\Sigma_c^{*+} \to \Sigma_c^+\gamma$	0.001	0.010
$\Xi_c^{*+} \to \Xi_c'^+\gamma$	0.030	0.049
$\Omega_c^{*0} \to \Omega_c^0\gamma$	1.142	1.250
$\Xi_{cc}^{*+} \to \Xi_{cc}^+\gamma$	1.963	1.752
$\Omega_{cc}^{*+} \to \Omega_{cc}^+\gamma$	1.969	1.789

Conclusions

Isospin breaking effects:

- Breaking of isospin symmetry have negligible effects (~ 2%) in the transition magnetic moments and radiative decay widths of charm baryons.

Screening effects:

- Effect of screening gradually decreases in magnetic moments from light to heavy flavor owing to the variation of the screened charge parameter, when the size of the baryon is expected to decrease.
- Variation of numerical values of transition magnetic moments and M1 decay widths can be explained as a consequence of the accumulation of individual magnetic moments of constituent quarks with respective signs and effective quark charge due to screening.
- Magnetic moments of constituent quarks add constructively or destructively along with the effective charge of quarks, which can produce a screening effect of $O(10\%)$ or more.

Quark charge screening acts as the major source of variation in the magnetic properties of baryons, compared to isospin breaking.

References

1. A. De Rujula, H. Georgi and S. L. Glashow, Phys. Rev. D **12** 147-162 (1975).
2. R. Dhir, C. S. Kim and R. C. Verma, Phys. Rev. D **88** 094002 (2013).
3. A. Hazra, S. Rakshit, and R. Dhir, Phys. Rev. D **104**, 053002 (2021).
4. R. L. Workman et al. [Particle Data Group], PTEP **2022**, 083C01 (2022).
5. B. Mohan, T. M. S., A. Hazra, R. Dhir, Phys. Rev. D **106**, no. 11, 113007 (2022).