Radiative M1 decays of charm baryons in screened quark charge scheme

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INTRODUCTION

The tremendous amount of experimental activity at the LHCb, CMS, BES-III collaborations over the past decade has inspired the heavy flavor physicists to explore the heavy-quark dynamics in depth. The radiative decay processes, namely, $\Omega_c^{*0} \to \Omega_c^0\gamma$, $\Xi_c'^{+} \to \Xi_c^{+}\gamma$, and $\Xi_c'^{0} \to \Xi_c^{0}\gamma$, were observed but not measured experimentally by the BaBar and Belle collaborations [1]. Motivated by the precise experimental measurements of heavy flavor baryon masses, we calculate the radiative M1 decay widths of charm baryons for $\frac{1}{2}'^{+} \to \frac{1}{2}^{+}$ and $\frac{3}{2}^{+} \to \frac{1}{2}^{(\prime)+}$ transitions. We employ the effective mass scheme (EMS) in addition to the screening of quark charge (referred as screened quark charge scheme (SQCS)) for calculating the M1 decay widths of aforementioned transitions.

THEORETICAL FRAMEWORK

The charge of a quark inside a baryon gets modified due to the presence of neighboring quarks, analogous to the modification of quark mass due to its surroundings [2, 3]. Thus, the effective charge of a quark i inside a baryon, $B(i\ j\ k)$ as:

$$e_i^B = e_i + \alpha_{ij} e_j + \alpha_{ik} e_k, \tag{1}$$

where e_i, e_j, and e_k are the bare charges of quarks i, j, and k, respectively. Here, α_{ij} and α_{ik} are the screening parameters of quark i due to the spectator quarks j and k, respectively. In the current work, we define the magnetic moment operator as,

$$\boldsymbol{\mu} = \sum_i \frac{e_i + \alpha_{ij} e_j + \alpha_{ik} e_k}{2m_i^B} \boldsymbol{\sigma_i} = \sum_i \frac{e_i^B}{2m_i^B} \boldsymbol{\sigma_i}, \tag{2}$$

where $i = u,\ d,\ s,$ and c; $\boldsymbol{\sigma_i}$ is the Pauli's spin matrix; e_i^B and m_i^B represents the effective charge and effective mass of i^{th} quark, respectively. We calculate the M1 decay widths for $B'^{(*)} \to B^{(\prime)}\gamma$ transitions utilizing the following relation:

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

where

$$\omega = \frac{M_{B'^{(*)}}^2 - M_{B^{(\prime)}}^2}{2M_{B'^{(*)}}} \tag{4}$$

is the photon momentum in the rest frame of the decaying baryon. Here, $\alpha \approx \frac{1}{137}$ is the fine structure constant, M_p is the mass of proton, J is the spin quantum number of the decaying baryon state, $M_{B'^{(*)}}$ and $M_{B^{(\prime)}}$ are the masses of initial and final baryon, respectively. The transition moments, $\mu_{B'^{(*)} \to B^{(\prime)}}$ is expressed in μ_N.

RESULTS AND DISCUSSIONS

Using the input values of constituent quark masses and screened charge parameters from our recent work [4], we obtain the numerical results for the radiative M1 decay widths of charm baryons in both EMS and SQCS, as shown in TABLE I. We focus on our

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TABLE I. Radiative M1 decay widths of charm baryons (in keV).

Transitions	EMS	SQCS	BM
		$z = 0.021(0.155)$	[5]
$\Sigma_c^+ \to \Lambda_c^+\gamma$	93.70	75.46(75.54)	74.10
$\Xi_c^{\prime +} \to \Xi_c^+\gamma$	21.29	16.86(18.18)	18.60
$\Xi_c^{\prime 0} \to \Xi_c^0\gamma$	0.327	0.389(0.233)	0.185
$\Sigma_c^{*+} \to \Lambda_c^+\gamma$	231.6	186.6(187.0)	190.0
$\Xi_c^{*+} \to \Xi_c^+\gamma$	81.58	64.58(69.50)	81.60
$\Xi_c^{*0} \to \Xi_c^0\gamma$	1.263	1.503(0.902)	0.745
$\Sigma_c^{*++} \to \Sigma_c^{++}\gamma$	1.487	1.964(2.278)	1.960
$\Sigma_c^{*+} \to \Sigma_c^+\gamma$	0.001	0.010(0.081)	0.011
$\Sigma_c^{*0} \to \Sigma_c^0\gamma$	1.370	1.468(0.900)	1.410
$\Xi_c^{*+} \to \Xi_c^{\prime +}\gamma$	0.030	0.049(0.146)	0.063
$\Xi_c^{*0} \to \Xi_c^{\prime 0}\gamma$	1.263	1.396(0.875)	1.330
$\Omega_c^{*0} \to \Omega_c^0\gamma$	1.142	1.250(0.790)	1.130
$\Xi_{cc}^{*++} \to \Xi_{cc}^{++}\gamma$	2.390	2.595(4.070)	2.790
$\Xi_{cc}^{*+} \to \Xi_{cc}^+\gamma$	1.963	1.752(0.689)	2.170
$\Omega_{cc}^{*+} \to \Omega_{cc}^+\gamma$	1.969	1.789(0.844)	1.600

SQCS results of our best fit value for screened charge parameter in charm sector given by $z = 0.021$. The numerical values corresponding to $z = 0.155$ are also included which can be interpreted as the maximum effect of quark charge screening.

Our predictions for the singly charmed baryons are in very good agreement with those of bag model (BM) [5], with the exception of the $\Xi_c^{\prime 0} \to \Xi_c^0$ and $\Xi_c^{*0} \to \Xi_c^0$ transitions. The M1 decay widths for $\frac{3}{2}^+ \to \frac{1}{2}^+$ radiative transitions are larger than those for $\frac{3}{2}^+ \to \frac{1}{2}^{\prime +}$ due to the spin flip of the light quarks. This observation holds true in most theoretical models, including our own. However, the $\Xi_c^{*0} \to \Xi_c^0$ transition stands out as an exception to this. On the other hand, our SQCS results are fractionally smaller than those from EMS and BM [5] for doubly charmed baryons. Our analysis indicates that the screening effect in the radiative decay widths of charmed baryons introduces an average change of 20% in the numerical values, excluding the $\Sigma_c^{*+} \to \Sigma_c^+$ transition. In addition, corresponding to the maximum screening effect at $z = 0.155$, the numerical results exhibit very large changes in the associated numerical values; however, these changes are still within acceptable ranges when compared to other theoretical models. It is important to note that the effect of screening reduces to an average of $\mathcal{O}(10\%)$ as we approach the doubly charmed baryons.

We conclude that the variations in the SQCS results in comparison to the EMS indicates that the quark charge screening has a significant effect on the radiative M1 decay widths of charm baryons. We have also noted that, with the increase in mass of quarks the effect of screening reduces, owing to the variation of the screened charge parameter [4]. This implies that, the heavy quarks are less affected by the screening of the neighbouring quarks as compared to the light sector. Interestingly, the effect of screening gradually decreases with the increase in mass of the baryon, when the size of the baryon is expected to decrease. We believe that the future experimental and theoretical endeavours in heavy flavor physics will validate our work.

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