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Axial-vector meson emitting weak nonleptonic decays of bottom baryons

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We investigate the two-body weak nonleptonic decays of Λ_b^0, Ξ_b^0, and Ξ_b^- into the octet baryons ($J^P = 1/2^+$) and axial-vector mesons ($J^P = 1^+$) employing the factorization scheme and obtain their branching ratios and asymmetry parameters.

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I. INTRODUCTION

The nonleptonic weak decays of hadrons provide insight into the interplay of strong with weak interactions. Theoretically, most of the attention has been paid to understand the weak decays of the heavy flavor mesons. Although the experimental data [1–5] and theoretical predictions [6–13] on the nonleptonic decays of charm baryons have become available in the past decade, the data on bottom baryons has merely begun. Some attempts have already been made [14–16] to study the weak hadronic decays of bottom baryons emitting s-wave mesons mainly. Recently, the lifetime and masses of Λ_b^0, Ξ_b^0, and Ξ_b^- have been measured. These bottom baryons, being heavy, can emit p-wave axial-vector mesons also [17]. One particular decay, $\Lambda_b^0 \to \Lambda_c^+ a_1^-$, has already been seen but its branching ratio has not yet been measured. In light of these developments, we here present theoretical estimates for weak nonleptonic decays of Λ_b^0, Ξ_b^0, and Ξ_b^- into the octet baryons ($J^P = 1/2^+$) and axial-vector mesons ($J^P = 1^+$). Employing the factorization scheme in the nonrelativistic quark model (NRQM) and the heavy quark effective theory (HQET) considerations, we estimate the branching ratios and asymmetry parameters for Λ_b^0, Ξ_b^0, and Ξ_b^- decays.

The layout of this paper is as follows. Section II describes the meson spectroscopy. Section III deals with basic methodology including the weak Hamiltonian, kinematics, form factors, and decay constants involved in the weak decays. In the last section, discussion of results and conclusions are given.

II. MESON SPECTROSCOPY

Both types of axial-vector mesons, ${}^3P_1(J^{PC} = 1^{++})$ and ${}^1P_1(J^{PC} = 1^{+-})$, behave well with respect to the quark model $q\bar{q}$ assignments. Strange and charmed states made up of different flavors are given by a mixture of ${}^3P_1$ and ${}^1P_1$ states, since there is no quantum number forbidding such mixing. In contrast, diagonal ${}^3P_1$ and ${}^1P_1$ states have opposite C-parity and cannot mix. Experimentally [1], the following nonstrange and uncharmed mesons have been observed:

(i) for ${}^3P_1$ multiplet, isovector $a_1(1.260)$ and three isoscalars $f_1(1.285)$, $f_1'(1.510)$, and $\chi_{c1}(3.510)$. Numbers given in the brackets indicate mass (in GeV) of the respective mesons.

(ii) for ${}^1P_1$ multiplet, isovector $b_1(1.235)$ and three isoscalars $h_1(1.170)$, $h_1'(1.380)$, and $h_{c1}(3.525)$. Spin and parity of the $h_{c1}(3.525)$ remains to be confirmed.

In the present analysis, mixing of the isoscalar states of (1^{++}) mesons is defined as

$$\begin{aligned} f_1(1.285) &= \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\cos\varphi_A + (s\bar{s})\sin\varphi_A, \\ f_1'(1.510) &= \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\sin\varphi_A - (s\bar{s})\cos\varphi_A. \qquad (1) \\ \chi_{c1}(3.510) &= (c\bar{c}), \end{aligned}$$

where

$$\phi_A = \theta(\text{ideal}) - \theta_A(\text{physical}).$$

Similarly, mixing of the two isoscalar mesons $h_1(1.170)$ and $h_1'(1.380)$ is defined as

$$\begin{aligned} h_1(1.170) &= \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\cos\phi_{A'} + (s\bar{s})\sin\phi_{A'}, \\ h_1'(1.380) &= \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d})\sin\phi_{A'} - (s\bar{s})\cos\phi_{A'}. \qquad (2) \\ h_{c1}(3.525) &= (c\bar{c}). \end{aligned}$$

Proximity of $a_1(1.260)$ and $f_1(1.285)$ and to lesser extent that of $b_1(1.235)$ and $h_1(1.170)$ indicates the ideal mixing for both 1^{++} and 1^{+-} nonets, i.e.,

$$\phi_A = \phi_{A'} = 0°. \qquad (3)$$

States involving a strange quark of $A(J^{PC} = 1^{++})$ and $B(J^{PC} = 1^{+-})$ mesons mix to generate the physical states in the following manner:

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$$K_1(1.270) = K_{1A}\sin\theta_1 + K_{1B}\cos\theta_1,$$
$$\underline{K}_1(1.400) = K_{1A}\cos\theta_1 - K_{1B}\sin\theta_1, \qquad (4)$$

where K_{1A} and K_{1B} denote the strange partners of $a_1(1.260)$ and $b_1(1.235)$, respectively. The Particle Data Group [1] assumes that the mixing is maximal, i.e., $\theta_1 = 45°$, whereas $\tau \to K_1(1.270)/K_1(1.400) + \nu_\tau$ data yields $\theta_1 = \pm 37°$ and $\theta_1 = \pm 58°$ [18]. However, the study of $D \to K_1(1.270)\pi$, $K_1(1.400)\pi$ decays rules out positive mixing-angle solutions. Therefore, both negative mixing-angle solutions are allowed by experiment as discussed in detail in Ref. [19]. But $D \to K_1^-(1.400)\pi^+$ is very suppressed for $\theta_1 = -37°$ and favors the other solution $\theta_1 = -58°$ [19]. Hence, we take $\theta_1 = -58°$ in our analysis.

The mixing of charmed and strange charmed states is given by

$$D_1(2.422) = D_{1A}\sin\theta_{D_1} + D_{1B}\cos\theta_{D_1},$$
$$\underline{D}_1(2.427) = D_{1A}\cos\theta_{D_1} - D_{1B}\sin\theta_{D_1}, \qquad (5)$$

and

$$D_{s1}(2.460) = D_{s1A}\sin\theta_{D_{s1}} + D_{s1B}\cos\theta_{D_{s1}},$$
$$\underline{D}_{s1}(2.536) = D_{s1A}\cos\theta_{D_{s1}} - D_{s1B}\sin\theta_{D_{s1}}. \qquad (6)$$

However, in the heavy quark limit, the physical mass eigenstates with $J^P = 1^+$ are $P_1^{3/2}$ and $P_1^{1/2}$ rather than $^3P_1$ and $^1P_1$ states as the heavy quark spin S_Q decouples from the other degrees of freedom so that S_Q and the total angular momentum of the light antiquark are separately good quantum numbers. Therefore, we can write

$$|P_1^{1/2}\rangle = -\sqrt{\tfrac{1}{3}}|^1P_1\rangle + \sqrt{\tfrac{2}{3}}|^3P_1\rangle,$$
$$|P_1^{3/2}\rangle = \sqrt{\tfrac{2}{3}}|^1P_1\rangle + \sqrt{\tfrac{1}{3}}|^3P_1\rangle. \qquad (7)$$

Hence, the states $D_1(2.422)$ and $D_{1-}(2.427)$ can be identified with $P_1^{1/2}$ and $P_1^{3/2}$, respectively. However, beyond the heavy quark limit, there is a mixing between $P_1^{1/2}$ and $P_1^{3/2}$, denoted by

$$D_1(2.422) = D_1^{1/2}\cos\theta_2 + D_1^{3/2}\sin\theta_2,$$
$$\underline{D}_1(2.427) = -D_1^{1/2}\sin\theta_2 + D_1^{3/2}\cos\theta_2. \qquad (8)$$

Likewise for strange axial-vector charmed mesons,

$$D_{s1}(2.460) = D_{s1}^{1/2}\cos\theta_3 + D_{s1}^{3/2}\sin\theta_3,$$
$$\underline{D}_{s1}(2.536) = -D_{s1}^{1/2}\sin\theta_3 + D_{s1}^{3/2}\cos\theta_3. \qquad (9)$$

The mixing angle $\theta_2 = (5.7 \pm 2.4)°$ is obtained by Belle through a detailed $B \to D^*\pi\pi$ analysis [20], while $\theta_3 \approx 7°$ is determined from the quark potential model [21,22].

III. METHODOLOGY

A. Weak Hamiltonian

For bottom changing $\Delta b = 1$ decays involving $b \to c$ transition, QCD modified weak Hamiltonian is given below:

$$\begin{aligned} H_W = \frac{G_F}{\sqrt{2}}\{&V_{cb}V_{ud}^*[a_1(\bar{c}b)(\bar{d}u) + a_2(\bar{d}b)(\bar{c}u)] \\ &+ V_{cb}V_{cs}^*[a_1(\bar{c}b)(\bar{s}c) + a_2(\bar{s}b)(\bar{c}c)] \\ &+ V_{cb}V_{us}^*[a_1(\bar{c}b)(\bar{s}u) + a_2(\bar{s}b)(\bar{c}u)] \\ &+ V_{cb}V_{cd}^*[a_1(\bar{c}b)(\bar{d}c) + a_2(\bar{d}b)(\bar{c}c)]\}, \end{aligned} \qquad (10)$$

where $(\bar{q}_iq_j) \equiv \bar{q}_i\gamma_\mu(1-\gamma_5)q_j$ denotes the weak V-A current. We follow the convention of the large N_c limit to fix QCD coefficients $a_1 \approx c_1$ and $a_2 \approx c_2$, where [23]

$$\begin{aligned} c_1(\mu) &= 1.26, \quad c_2(\mu) = -0.51 \quad \text{at } \mu \approx m_c^2, \\ c_1(\mu) &= 1.12, \quad c_2(\mu) = -0.26 \quad \text{at } \mu \approx m_b^2. \end{aligned} \qquad (11)$$

B. Kinematics

Following the standard procedure for baryon decays [6,24], the matrix element for the $B_i(1/2^+) \to B_f(1/2^+) + A_k(1^+)$ decay process can be written as

$$\begin{aligned} &\langle B_f(p_f)A_k(q)|H_W|B_i(p_i)\rangle \\ &= i\bar{u}_{B_f}(p_f)\varepsilon^{*\mu}(A_1\gamma_\mu\gamma_5 + A_2p_{f\mu}\gamma_5 + B_1\gamma_\mu + B_2p_{f\mu}) \\ &\quad \times u_{B_i}(p_i), \end{aligned}$$

where ε^μ is the polarization vector of the axial-vector meson A_k. Here A_i's and B_i's denote the parity conserving (PC) and parity violating (PV) amplitudes, respectively. The decay width is given by

$$\begin{aligned} \Gamma = \frac{q_\mu}{8\pi}\frac{E_f + m_f}{m_i}\bigg[&2(|S|^2 + |P_2|^2) \\ &+ \frac{E_A^2}{m_A^2}(|S + D|^2 + |P_1|^2)\bigg], \end{aligned} \qquad (12)$$

and asymmetry parameter is

$$\alpha = \frac{4m_A^2\,\mathrm{Re}(S * P_2) + 2E_A^2\,\mathrm{Re}(S + D) * P_1}{2m_A^2(|S|^2 + |P_2|^2) + E_A^2(|S + D|^2 + |P_1|^2)}, \qquad (13)$$

with

$$\begin{aligned} S &= -A_1, \\ P_1 &= -\frac{q_\mu}{E_A}\left(\frac{m_i + m_f}{E_f + m_f}B_1 + m_iB_2\right), \\ P_2 &= \frac{q_\mu}{E_f + m_f}B_1, \\ D &= -\frac{q_\mu^2}{E_A(E_f + m_f)}(A_1 - m_iA_2), \end{aligned} \qquad (14)$$

and

$$|q_\mu| = \frac{1}{2m_i}\sqrt{[m_i^2 - (m_f - m_A)^2][m_i^2 - (m_f + m_A)^2]},$$

where $q_\mu = (p_i - p_f)_\mu$ is the four momentum of the axial-vector meson in the rest frame of the parent particle, m_i and m_f are the masses of the initial and final baryons, and m_A is the emitted meson mass. E_A and E_f are the energies of the axial-vector meson and the daughter baryon, respectively.

In general, weak hadronic decays of the baryons obtain contributions from W-emission and W-exchange diagrams, which are usually calculated as factorizable and pole diagrams. Though for weak hadronic decays of hyperons and charm baryons, W-exchange effects are comparable to the factorization terms, we expect pole terms to be relatively small for the bottom baryon decays due to the large bottom baryon masses. Therefore, to obtain the preliminary estimate of the branching ratios of the decays considered here, we include the factorizable contributions only. In the standard factorization scheme [6], the separable combination of decay amplitudes for $B_i(1/2^+) \to B_f(1/2^+) + A_k(1^+)$ is given by

$$\langle A_k(q)|A_\mu|0\rangle\langle B_f(p_f)|V^\mu - A^\mu|B_i(p_i)\rangle \tag{15}$$

apart from the scale factors. The first factor is written as

$$\langle A_k(q)|(\bar{q}_1 q_2)|0\rangle = f_A m_A \varepsilon_\mu^*, \tag{16}$$

where f_A is the decay constant of the emitted axial-vector meson A_k. Matrix elements of the weak currents between baryon states are

$$\langle B_f(p_f)|V_\mu|B_i(p_i)\rangle = \bar{u}_f(p_f)\left[f_1\gamma_\mu - \frac{f_2}{m_i}i\sigma_{\mu\nu}q^\nu + \frac{f_3}{m_i}q_\mu\right]u_i(p_i) \tag{17}$$

and

$$\langle B_f(p_f)|A_\mu|B(p_i)\rangle = \bar{u}_f(p_f)\left[g_1\gamma_\mu\gamma_5 - \frac{g_2}{m_i}i\sigma_{\mu\nu}q^\nu\gamma_5 + \frac{g_3}{m_i}q_\mu\gamma_5\right]u_i(p_i). \tag{18}$$

The factorizable amplitudes are thus given by

$$\begin{aligned}
A_1^{\rm fac} &= -\frac{G_F}{\sqrt{2}}F_C f_A c_k m_A\left[g_1^{B_i,B_f}(m_A^2) - g_2^{B_i,B_f}(m_A^2)\frac{m_i - m_f}{m_i}\right],\\
A_2^{\rm fac} &= \frac{G_F}{\sqrt{2}}F_C f_A c_k m_A[2g_2^{B_i,B_f}(m_A^2)/m_i],\\
B_1^{\rm fac} &= \frac{G_F}{\sqrt{2}}F_C f_A c_k m_A\left[f_1^{B_i,B_f}(m_A^2) + f_2^{B_i,B_f}(m_A^2)\frac{m_i + m_f}{m_i}\right]\\
B_2^{\rm fac} &= -\frac{G_F}{\sqrt{2}}F_C f_A c_k m_A[2f_2^{B_i,B_f}(m_A^2)/m_i],
\end{aligned} \tag{19}$$

where F_C contains appropriate Cabibbo-Kobayashi-Maskawa factors and Clebsch-Gordan coefficients.

C. Form factors and decay constants

Determination of the baryonic form factors in the quark model is not straightforward due to their having three-quark structure, and several corrections, like q^2 dependence of the form factors and hard gluon QCD contributions. Moreover, the form factors for baryon-baryon transitions are expected to satisfy the constraints imposed by the heavy quark symmetry. Charm changing baryon-baryon transition form factors have been evaluated by Perez-Marcial *et al.* [25] in the nonrelativistic quark model (NRQM). We extend their analysis to calculate bottom changing baryon-baryon transition form factors which are given in column 2 of Table I. However, it has been pointed out by Cheng and Tseng [26] that the relations between form factors at zero recoil, which are given by the heavy quark symmetry, are not respected by baryon-baryon form factors obtained in the nonrelativistic quark model. In order to improve the quark model calculations, in consistency with the features of the heavy quark symmetry, they have calculated the $1/M$ corrections to form factors using the heavy quark effective theory (HQET) considerations. We have employed their formalism to recalculate the heavy-heavy and heavy-light transition form factors using our phase convention. The calculated form factors are given in column 3 of Table I. In light of the large $1/M$ corrections, the results obtained in NRQM may not be reliable. Therefore, considering the theoretical uncertainties in the evaluation of the form factors, which would obviously affect the branching ratios, we have calculated the branching ratios in both of these models.

Let us now turn to the decay constants of the axial-vector mesons. The decay constant of the $J^{PC} = 1^{+-}$ axial-vector mesons is suppressed due to the C-parity behavior. Under charge conjunction, the two types of axial-vector mesons transform as

$$\begin{aligned}
M_b^a(1^{++}) &\to +M_a^b(1^{++})\\
M_b^a(1^{+-}) &\to -M_a^b(1^{+-}) \qquad (a, b = 1, 2, 3),
\end{aligned} \tag{20}$$

where M_b^a denotes meson 3×3 matrix elements in SU(3) flavor symmetry. Since the weak axial-vector current transforms as $(A_\mu)_b^a \to +(A_\mu)_a^b$ under charge conjunction, only the (1^{++}) state can be produced through the axial-vector current in the SU(3) symmetry limit [18].

To determine the decay constant of $K_1(1.270)$, we use the following formula:

$$\Gamma(\tau \to K_1\nu_\tau) = \frac{G_F^2}{16\pi}|V_{us}|^2 f_{K_1}^2\frac{(m_\tau^2 + 2m_{K_1}^2)(m_\tau^2 - m_{K_1}^2)^2}{m_\tau^3}, \tag{21}$$

which gives $f_{K_1(1270)} = 0.175 \pm 0.019$ GeV. The decay constant of $K_1(1.400)$ can be simply related to $K_1(1.270)$

TABLE I. Baryon to baryon form factors at $q^2 = 0$.

Decay	Using NRQM [25]				Based on HQET considerations [26]			
	f_1	f_2	g_1	g_2	f_1	f_2	g_1	g_2
$\Lambda_b^0 \to \Lambda_c^+$	0.310	0.170	0.530	−0.044	0.547	0.103	0.592	0.013
$\Lambda_b^0 \to n$	0.067	−0.110	−0.098	0.019	−0.045	−0.024	−0.090	−0.020
$\Lambda_b^0 \to \Lambda$	−0.058	0.130	0.120	−0.021	0.061	0.025	0.100	0.013
$\Xi_b^0 \to \Xi_c^+$	0.330	0.150	0.540	−0.041	0.554	0.129	0.590	0.019
$\Xi_b^0 \to \Lambda$	−0.018	0.036	0.040	−0.007	0.020	0.012	0.039	0.012
$\Xi_b^0 \to \Sigma^0$	−0.029	0.070	0.081	−0.014	0.043	0.028	0.080	0.026
$\Xi_b^0 \to \Xi^0$	0.039	−0.130	−0.160	0.024	−0.083	−0.041	−0.130	−0.024
$\Xi_b^- \to \Xi_c^0$	0.330	0.150	0.530	−0.041	0.554	0.129	0.590	0.019
$\Xi_b^- \to \Sigma^-$	−0.039	0.092	0.110	−0.018	0.063	0.040	0.113	0.037
$\Xi_b^- \to \Xi^-$	0.037	−0.120	−0.150	0.024	−0.084	−0.041	−0.131	−0.025

in SU(3) limit as $f_{K_1(1.400)}/f_{K_1(1.270)} = \cot\theta_1$. A small value around 0.011 GeV for the decay constant of K_{1B} may arise through SU(3) breaking, which yields

$$f_{\underline{K}_1(1.400)} = f_{K_{1A}} \cos\theta_1 - f_{K_{1B}} \sin\theta_1 = -0.087 \text{ GeV}, \tag{22}$$

for $\theta_1 = -58°$ [22]. Similarly, the decay constant of $a_1(1.260)$ can be obtained from $B(\tau \to a_1 \nu_\tau)$. However, this branching ratio is not given by Particle Data Group [1], although the data on $\tau \to a_1 \nu_\tau \to \rho\pi\nu_\tau$ have been reported by various experiments. We take $f_{a_1} = 0.203 \pm 0.018$ GeV from the analysis given by Bloch *et. al.* [27]. For the decay constant of $f_1(1.285)$, we assume $f_{f_1} \approx f_{a_1}$.

The decay constants

$$f_{D_{1A}} = -0.127 \text{ GeV}, \qquad f_{D_{1B}} = 0.045 \text{ GeV},$$
$$f_{D_{s1A}} = -0.121 \text{ GeV}, \qquad f_{D_{s1B}} = 0.038 \text{ GeV} \tag{23}$$

have been taken from [22] and determine $f_{\chi_{c1}} \approx -0.160$ GeV [22].

IV. DISCUSSION OF RESULTS AND CONCLUSIONS

Substituting various quantities in the decay amplitudes given in Eq. (19), and using Eqs. (12) and (13), we now compute the branching ratios and asymmetry parameters

TABLE II. Branching ratio and asymmetry for Λ_b^0 decays.

Decay	Branching ratio (%)	Asymmetry "α"	Branching ratio (%)	Asymmetry "α"
	Using the form factors obtained in column 2 of Table I		Using the form factors obtained in column 3 of Table I	
$\Delta C = 1$, $\Delta S = 0$				
$\Lambda_b^0 \to \Lambda_c^+ a_1^-$	0.58	−0.53	0.90	−0.73
$\Lambda_b^0 \to n D_1^0$	1.4×10^{-3}	0.74	9.2×10^{-4}	−0.31
$\Lambda_b^0 \to n D_{-1}^0$	4.9×10^{-5}	0.74	3.1×10^{-5}	−0.31
$\Delta C = 0$, $\Delta S = -1$				
$\Lambda_b^0 \to \Lambda_c^+ D_{s1}^-$	0.33	−0.084	0.42	−0.24
$\Lambda_b^0 \to \Lambda_c^+ D_{-s1}^-$	0.016	−0.064	0.021	−0.22
$\Lambda_b^0 \to \Lambda \chi_{c1}$	7.0×10^{-3}	0.49	3.7×10^{-3}	0.001
$\Delta C = 1$, $\Delta S = -1$				
$\Lambda_b^0 \to \Lambda_c^+ K_1^-$	0.024	−0.51	0.037	−0.71
$\Lambda_b^0 \to \Lambda_c^+ K_{-1}^-$	7.9×10^{-3}	−0.46	0.012	−0.66
$\Lambda_b^0 \to \Lambda D_1^0$	1.0×10^{-4}	0.62	6.1×10^{-5}	−0.31
$\Lambda_b^0 \to \Lambda D_{-1}^0$	3.5×10^{-6}	0.62	2.1×10^{-6}	−0.31
$\Delta C = 0$, $\Delta S = 0$				
$\Lambda_b^0 \to \Lambda_c^+ D_1^-$	0.019	−0.092	0.025	−0.26
$\Lambda_b^0 \to \Lambda_c^+ D_{-1}^-$	6.7×10^{-4}	−0.093	8.5×10^{-4}	−0.26
$\Lambda_b^0 \to n \chi_{c1}$	2.7×10^{-4}	0.58	1.6×10^{-4}	−0.003

TABLE III. Branching ratio and asymmetry for Ξ_b^0 decays.

Decay	Branching ratio (%) Using the form factors obtained in column 2 of Table I	Asymmetry "α" Using the form factors obtained in column 2 of Table I	Branching ratio (%) Using the form factors obtained in column 3 of Table I	Asymmetry "α" Using the form factors obtained in column 3 of Table I
$\Delta C = 1$, $\Delta S = 0$				
$\Xi_b^0 \to \Xi_c^+ a_1^-$	0.63	−0.57	0.93	−0.73
$\Xi_b^0 \to \Lambda D_1^0$	2.4×10^{-4}	0.58	1.8×10^{-4}	−0.32
$\Xi_b^0 \to \Lambda D_{-1}^0$	8.3×10^{-6}	0.58	6.3×10^{-6}	−0.32
$\Xi_b^0 \to \Sigma^0 D_1^0$	9.5×10^{-4}	0.52	7.7×10^{-4}	−0.33
$\Xi_b^0 \to \Sigma^0 D_{-1}^0$	3.2×10^{-5}	0.52	2.7×10^{-5}	−0.33
$\Delta C = 0$, $\Delta S = -1$				
$\Xi_b^0 \to \Xi_c^+ D_{s1}^-$	0.35	−0.12	0.44	−0.24
$\Xi_b^0 \to \Xi_c^+ D_{-s1}^-$	0.018	−0.096	0.022	−0.22
$\Xi_b^0 \to \Xi^0 \chi_{c1}$	0.012	0.39	7.0×10^{-3}	0.0008
$\Delta C = 1$, $\Delta S = -1$				
$\Xi_b^0 \to \Xi_c^+ K_1^-$	0.026	−0.55	0.039	−0.71
$\Xi_b^0 \to \Xi_c^+ K_{-1}^-$	8.4×10^{-3}	−0.50	0.012	−0.66
$\Xi_b^0 \to \Xi^0 D_1^0$	1.7×10^{-4}	0.44	1.1×10^{-4}	−0.32
$\Xi_b^0 \to \Xi^0 D_{-1}^0$	5.9×10^{-6}	0.44	3.9×10^{-6}	−0.32
$\Delta C = 0$, $\Delta S = 0$				
$\Xi_b^0 \to \Xi_c^+ D_1^-$	0.021	−0.13	0.026	−0.25
$\Xi_b^0 \to \Xi_c^+ D_{-1}^-$	7.1×10^{-4}	−0.13	8.9×10^{-4}	−0.25
$\Xi_b^0 \to \Lambda \chi_{c1}$	4.9×10^{-5}	0.47	3.2×10^{-5}	−0.015
$\Xi_b^0 \to \Sigma^0 \chi_{c1}$	1.9×10^{-4}	0.43	1.3×10^{-4}	−0.007

TABLE IV. Branching ratio and asymmetry for Ξ_b^- decays.

Decay	Branching ratio (%) Using the form factors obtained in column 2 of Table I	Asymmetry "α" Using the form factors obtained in column 2 of Table I	Branching ratio (%) Using the form factors obtained in column 3 of Table I	Asymmetry "α" Using the form factors obtained in column 3 of Table I
$\Delta C = 1$, $\Delta S = 0$				
$\Xi_b^- \to \Xi_c^0 a_1^-$	0.63	−0.57	0.93	−0.73
$\Xi_b^- \to \Sigma^- D_1^0$	1.9×10^{-3}	0.52	1.6×10^{-3}	−0.33
$\Xi_b^- \to \Sigma^- D_{-1}^0$	6.6×10^{-5}	0.52	5.4×10^{-5}	−0.33
$\Delta C = 0$, $\Delta S = -1$				
$\Xi_b^- \to \Xi_c^0 D_{s1}^-$	0.35	−0.12	0.44	−0.24
$\Xi_b^- \to \Xi_c^0 D_{-s1}^-$	0.018	−0.096	0.022	−0.22
$\Xi_b^- \to \Xi^- \chi_{c1}$	0.013	0.38	7.0×10^{-3}	0.002
$\Delta C = 1$, $\Delta S = -1$				
$\Xi_b^- \to \Xi_c^0 K_1^-$	0.026	−0.55	0.039	−0.71
$\Xi_b^- \to \Xi_c^0 K_{-1}^-$	8.5×10^{-3}	−0.50	0.012	−0.66
$\Xi_b^- \to \Xi^- D_1^0$	1.8×10^{-4}	0.43	1.2×10^{-4}	−0.32
$\Xi_b^- \to \Xi^- D_{-1}^0$	6.0×10^{-6}	0.43	3.9×10^{-6}	−0.32
$\Delta C = 0$, $\Delta S = 0$				
$\Xi_b^- \to \Xi_c^0 D_1^-$	0.021	−0.13	0.026	−0.25
$\Xi_b^- \to \Xi_c^0 D_{-1}^-$	7.1×10^{-4}	−0.13	8.9×10^{-4}	−0.25
$\Xi_b^- \to \Sigma^- \chi_{c1}$	3.9×10^{-4}	0.43	2.7×10^{-4}	−0.007

for Λ_b^0, Ξ_b^0, and Ξ_b^- decays. Results are given in Tables II, III, and IV. We conclude the following:

(1) The decays $\Lambda_b^0 \to \Lambda_c^+ a_1^- / \Lambda_c^+ D_{s1}^-$, $\Xi_b^0 \to \Xi_c^+ a_1^- / \Xi_c^+ D_{s1}^-$, and $\Xi_b^- \to \Xi_c^0 a_1^- / \Xi_c^0 D_{s1}^-$ are the dominant ones having branching ratios in the range 0.33%–0.95% in both models. These branching ratios may interest the experimentalists for their search. In addition, the decays $\Lambda_b^0 \to \Lambda_c^+ D_{-s1}^- / \Lambda_c^+ K_1^- / \Lambda_c^+ D_1^-$, $\Xi_b^0 \to \Xi_c^+ D_{-s1}^- / \Xi_c^+ K_1^- / \Xi_c^+ D_1^- / \Xi^0 \chi_{c1}$, and $\Xi_b^- \to \Xi_c^0 D_{-s1}^- / \Xi_c^0 K_1^- / \Xi_c^0 D_1^- / \Xi^- \chi_{c1}$ are also dominant having next order branching ratios in the range 0.01%–0.04%.

(2) The decays involving the b_1^- meson in the final state are forbidden in the isospin limit. However, the isospin symmetry breaking may generate $\Lambda_b^0 \to \Lambda_c^+ b_1^-$, $\Xi_b^0 \to \Xi_c^+ b_1^-$, and $\Xi_b^- \to \Xi_c^0 b_1^-$ decays, which in our analysis are found to have branching ratios of the order of 10^{-6}%.

(3) Though for weak hadronic decays of the hyperons and charm baryons, pole contributions are comparable to the factorization terms, we expect pole terms to be relatively small for the bottom baryon decays due to the large bottom baryon masses.

(4) Determination of the baryonic form factors is not reliable for several reasons, like complications due to three-quark dynamics, q^2 dependence, and hard gluon QCD contributions. The form factors obtained in the quark model for baryon-baryon transitions are also expected to satisfy the relations given by the heavy quark symmetry. It has been observed that the form factors given by NRQM [25] do not respect such relations and large $1/M$ corrections have been obtained using the HQET considerations [26]. Therefore, considering the theoretical uncertainties in the evaluation of the form factors, we have obtained the preliminary estimates of branching ratios in both of these models.

(5) Predicted branching ratios are of the same order in both models, however, asymmetry parameters of some of the decays show change in sign, observation of which would clarify the situation.

[1] C. Amsler *et al.* (Particle Data Group), Phys. Lett. B **667**, 1 (2008), and references therein.
[2] M. Diehl and G. Hiller, J. High Energy Phys. 06 (2001) 067.
[3] M. Mattson *et al.* (SELEX Collaboration), Phys. Rev. Lett. **89**, 112001 (2002).
[4] R. Ammar *et al.* (CLEO Collaboration), Phys. Rev. Lett. **89**, 171803 (2002).
[5] J.M. Link *et al.* (FOCUS Collaboration), Phys. Lett. B **571**, 139 (2003).
[6] H. Y. Cheng and B. Tseng, Phys. Rev. D **46**, 1042 (1992).
[7] T. Uppal, R. C. Verma, and M. P. Khanna, Phys. Rev. D **49**, 3417 (1994).
[8] M. A. Ivanov *et al.*, Phys. Rev. D **57**, 5632 (1998).
[9] B. Guberina and B. Melic, Eur. Phys. J. C **2**, 697 (1998); B. Guberina and H. Stefancic, Phys. Rev. D **65**, 114004 (2002).
[10] K. K. Sharma and R. C. Verma, Eur. J. C **7**, 217 (1999).
[11] R. C. Verma, Ind. J. Pure Appl. Phys. **38**, 395 (2000); E. N. Bukina *et al.*, Nucl. Phys. **B93**, 34 (2001).
[12] V. E. Lyubovitskij *et al.*, Prog. Part. Nucl. Phys. **50**, 329 (2003).
[13] A. Sharma and R. C. Verma, Phys. Rev. D **71**, 074024 (2005); **79**, 037506 (2009).
[14] H. Y. Cheng, Phys. Rev. D **56**, 2799 (1997).
[15] Sonali Sinha, M. P. Khanna, and R. C. Verma, Phys. Rev. D **57**, 4483 (1998).
[16] Fayyazuddin and Riazuddin, Phys. Rev. D **58**, 014016 (1998).
[17] M. R. Khodja, Fayyazuddin, and Riazuddin, Phys. Rev. D **60**, 053005 (1999).
[18] M. Suzuki, Phys. Rev. D **47**, 1252 (1993); **55**, 2840 (1997).
[19] H. Y. Cheng, Phys. Rev. D **67**, 094007 (2003).
[20] K. Abe *et al.* (Belle Collaboration), Phys. Rev. D **69**, 112002 (2004).
[21] H. Y. Cheng, Phys. Rev. D **68**, 094005 (2003).
[22] H. Y. Cheng and C. K. Chua, Phys. Rev. D **69**, 074025 (2004).
[23] A. Ali and C. Greub, Phys. Rev. D **57**, 2996 (1998).
[24] R. E. Marshak, X. Riazzudin, and C. P. Ryan, *Theory of Weak Interactions in Particle Physics* (Wiley, New York, 1969); M. D. Scadron and L. R. Thebaud, Phys. Rev. D **8**, 2190 (1973).
[25] R. Perez-Marcial *et al.*, Phys. Rev. D **40**, 2955 (1989).
[26] H. Y. Cheng and B. Tseng, Phys. Rev. D **53**, 1457 (1996).
[27] J. C. R. Bloch *et al.*, Phys. Rev. D **60**, 094007 (1999); **60**, 111502 (1999).