Bottom baryon decays in the pole model

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We analyze the two-body hadronic decays of bottom baryons in the framework of the pole model. We study the Cabibbo allowed decays $\Lambda_b^0 \rightarrow \Lambda_c^+ + \pi^-$, $\Lambda_b^0 \rightarrow \Sigma_c^+ + \pi^-$, $\Lambda_b^0 \rightarrow \Lambda_c^+ + D_s^-$, $\Xi_b^- \rightarrow \Xi_c^0 + \pi^-$, and Cabibbo suppressed decays $\Lambda_b^0 \rightarrow \Lambda_c^+ + K^-$, $\Lambda_b^0 \rightarrow \Sigma_c^+ + K^-$, $\Lambda_b^0 \rightarrow \Lambda_c^+ + D^-$. The calculated values of the decay rate are compared with the values obtained by Mannel *et al.* with the factorization approximation using heavy quark effective theory. [S0556-2821(98)06505-9]

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Despite the significant progress made in the study of heavy meson decays, advancement in the arena of heavy baryons, both theoretical and experimental, has been very slow [1]. From the theoretical point of view, the dynamics of nonleptonic weak decays of hadrons is expected to become simpler as the hadrons become heavier. For example, the factorization approach has been applied to the heavy meson decays with reasonable success. However, the situation is not very satisfactory for the baryon decays: while the hyperon decays are described with the help of current algebra [2–7], a reliable approach suited for investigating the weak decays of heavy baryons does not exist as yet. Neither current algebra nor factorization seems to be the ultimate tool to analyze the heavy baryon decays.

We analyze two-body hadronic decays of bottom baryons in the framework of the pole model, which is more general than current algebra since its use is not restricted to the soft meson limit and to the pseudoscalar meson final state, and compare the results with those obtained in the factorization approach. The pole model has been used earlier in the decays of hyperons [8], charmed baryons [9] and B mesons [10]. In the approximation where we assume the baryon pole to make the dominant contribution, we find that the pole contribution is not negligible in all decay modes. We only consider the parity-conserving amplitude because it is not easy to estimate the parity-violating amplitude in the pole model. Further, the baryon-to-baryon parity-violating transition vanishes in the flavor symmetry limit, and so the contribution to the parity-violating amplitude from $1/2^+$ baryons is expected to be small.

I. FRAMEWORK

We consider the baryon decay $B \rightarrow B' + P$, where P is a pseudoscalar meson, and write [8]

$$M(B_i \rightarrow B_f + P_j) = i\overline{u}_{B_f}(A + B\gamma_5)u_{B_i}\phi_M, \tag{1}$$

A and B are the parity-violating (s wave) and parity-conserving (p wave) amplitudes, respectively. In the pole model, one introduces a set of intermediate states into the decay process so that the weak and strong vertices become separated. In other words, the process under consideration passes through certain hadronic intermediate states which can be decomposed into two steps: production of these intermediate states in the strong process, following which the intermediate baryon then undergoes a weak transition to the final baryon. A and B are then given simply by the product of strong- and weak-coupling constants divided by the mass sum and mass difference, respectively, for A and B.

The decay amplitudes are given as [8]

$$A^{\text{pole}} = \frac{a_{B_i \rightarrow B_l} g_{B_l \rightarrow B_f P_j}}{(M_{B_i} + M_{B_l})} + \frac{g_{B_i \rightarrow B_m P_j} a_{B_m \rightarrow B_f}}{(M_{B_m} + M_{B_f})}, \tag{2}$$

$$B^{\text{pole}} = \frac{b_{B_i \rightarrow B_l} g_{B_l \rightarrow B_f P_j}}{(M_{B_i} - M_{B_l})} + \frac{g_{B_i \rightarrow B_m P_j} b_{B_m \rightarrow B_f}}{(M_{B_m} - M_{B_f})}, \tag{3}$$

where $g_{B_l \rightarrow B_f P_j}$ is the strong-coupling constant representing the process $B_l \rightarrow B_f P_j$, and $b_{B_i \rightarrow B_l}$ is the amplitude with which the weak transition $B_i \rightarrow B_l$ takes place. The decay amplitude is thus determined in terms of the strong-coupling constants and weak transition amplitudes. The pole diagrams for the processes under consideration are drawn in Fig. 1.

A. Strong-coupling constants

The SU(5) invariant Hamiltonian representing the strong transitions can be written as

$$H_{\text{strong}} = \sqrt{2}(g_d + g_f)\tfrac{1}{2}\overline{B}^{[m,n]b} B_{[m,n]a} P_b^a + \sqrt{2}(g_d - g_f)\overline{B}^{[m,b]n} B_{[m,a]n} P_b^a, \tag{4}$$

where $B_{[m,n]a}$, $\overline{B}^{[m,n]b}$, and P_b^a are the baryon, antibaryon, and meson quark wave functions, respectively [3], and $g_d(g_f)$ is the d- (f-) type strong-coupling constant. We take $g_d + g_f = 14$ and $g_d/g_f = 1.5$, so that $g_d = 8.4$ and $g_f = 5.6$. The values of symmetric and symmetry-broken coupling

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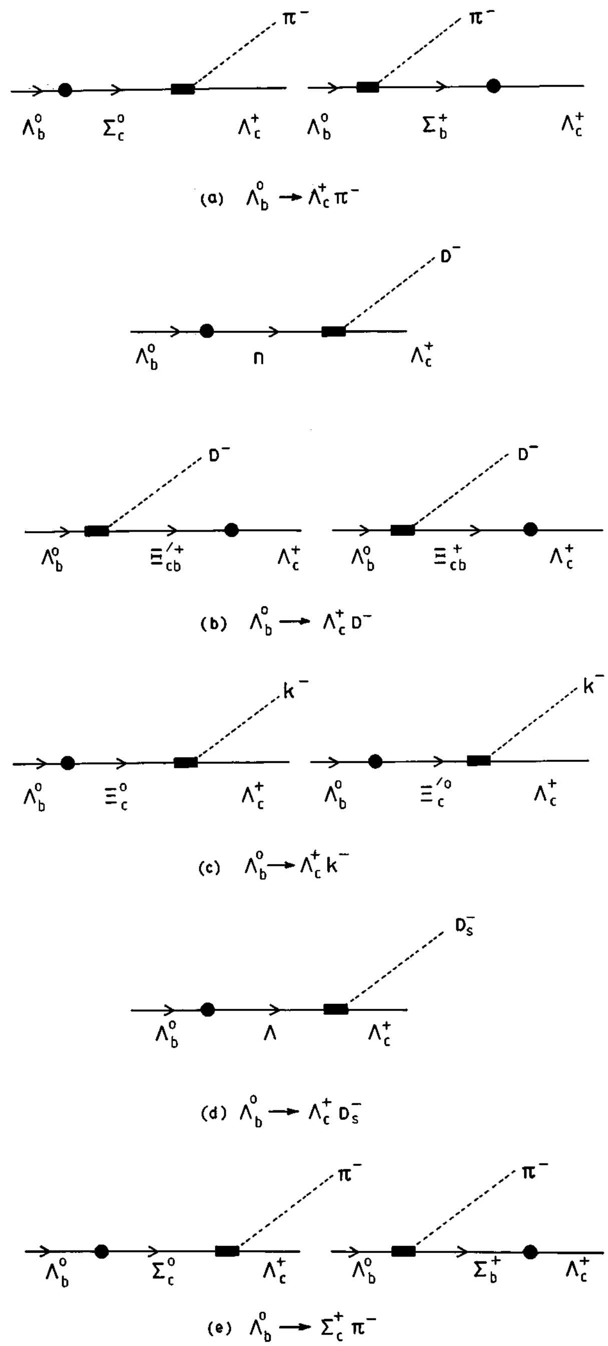

FIG. 1. Pole diagrams for pionic decays.

constants needed for the decays under consideration are tabulated in column (ii) of Table I. The symmetry-broken coupling constants are calculated from [11]

$$g_{ifj}^{\mathrm{SB}}=\frac{(M_i+M_f)}{2M_N}g_{ifj}^{\mathrm{Sym}},$$

and are tabulated in column (iii) of Table I. For the pion-emitted strong transitions, the above formula for the coupling constants is equivalent to using Goldberger-Treiman relation and symmetric values for the axial vector coupling constant. The estimation of the strong-coupling constants is, of course, suspect, as SU(5) is very badly broken symmetry.

B. Weak transition

The flavor symmetric and quark model Hamiltonian representing weak transitions is given by

$$H_{\mathrm{weak}}=V_{il}V_{jm}^{*}\overline{B}^{[i,j]k}B_{[l,m]k}H_{ij}^{lm}. \tag{5}$$

The spurion transforms like H_{15}^{24} [12]. The transition amplitude $a_{\Lambda_b\to\Sigma_c^0}$ is related to $a_{\Sigma^+\to p}$ by SU(5) or by quark model calculations. For calculational purposes, we take $a_{\Sigma^+\to p}=1.2\times10^{-7}$ GeV [6]. The weak transition elements are proportional to $V_{il}V_{jm}^{*}$, where V_{il} are Cabibbo-Kobayashi-Maskawa matrix elements. The relevant transition amplitudes are listed in Table II.

TABLE I. Strong-coupling constant values [Symmetric (Sym.) and symmetry broken (S.B.)].

Strong transition	Coupling constant (Sym.)	Coupling constant (S.B.)
$\Sigma_c^0 \to \Lambda_c^+ \pi^-$	$\frac{2}{\sqrt{3}} g_d = 9.39$	23.66
$\Sigma_c^0 \to \Sigma_c^+ \pi^-$	$2 g_f = 10.84$	28.28
$\Lambda_b^0 \to \Sigma_b^+ \pi^-$	$-\frac{2}{\sqrt{3}} g_d = -9.39$	-56.83
$\Xi_c^0 \to \Lambda_c^+ K^-$	$\sqrt{\frac{2}{3}} g_d = 6.64$	16.78
$n \to \Lambda^+ D^-$	$\sqrt{3} g_f + \frac{1}{\sqrt{3}} g_d = 14.08$	4.06
$\Lambda \to \Lambda_c^+ D_s^-$	$-\left(\sqrt{2} g_f + \frac{\sqrt{2}}{3} g_d\right) = -11.50$	-3.45
$\Xi_b^- \to \Xi_b^{\prime 0} \pi^-$	$\sqrt{\frac{2}{3}} g_d = 6.64$	16.78

II. DECAY RATE

The decay rate is

$$\Gamma(B_i \to B_f + P) = \frac{1}{4\pi} \frac{|\mathbf{q}|}{m_i} (E_f + m_f) \left[|A|^2 + \frac{E_f - m_f}{E_f + m_f} |B|^2 \right],$$

where

$$|\mathbf{q}| = \frac{1}{2m_i} [\{m_i^2 - (m_f + m_P)^2\}\{m_i^2 - (m_f - m_P)^2\}]^{1/2},$$

$$E_f + m_f = \frac{(m_i + m_f)^2 - m_P^2}{2m_i},$$

and

$$E_f - m_f = \frac{(m_i - m_f)^2 - m_P^2}{2m_i}.$$

We can also write the decay rate as

$$\Gamma = C_1[|A|^2 + C_2|B|^2],$$

where

$$C_1 = \frac{1}{8\pi} |\mathbf{q}| \frac{[(m_i + m_f)^2 - m_P^2]}{m_i^2},$$

$$C_2 = \frac{(m_i - m_f)^2 - m_P^2}{(m_i + m_f)^2 - m_P^2}.$$

TABLE II. Weak transition amplitude values.

Weak transition	Transition amplitude	Value (in units of 10^{-7})
$\Lambda_b^0 \to \Sigma_c^0$	$a_{\Lambda_b^0 \Sigma_c^0} = \frac{1}{\sqrt{6}} \frac{V_{cb}}{V_{us}} a_{\Sigma^+ p}$	0.0907
$\Sigma_b^+ \to \Lambda_c^+$	$a_{\Sigma_b^+ \Lambda_c^+} = -\frac{1}{\sqrt{6}} \frac{V_{cb}}{V_{us}} a_{\Sigma^+ p}$	-0.0907
$\Sigma_b^+ \to \Sigma_c^+$	$a_{\Sigma_b^+ \Sigma_c^+} = -\frac{1}{\sqrt{2}} \frac{V_{cb}}{V_{us}} a_{\Sigma^+ p}$	-0.1571
$\Lambda_b^0 \to \Xi_c^0$	$a_{\Lambda_b^0 \Xi_c^0} = -\frac{1}{6} V_{cb} a_{\Sigma^+ p}$	-0.0084
$\Lambda_b^0 \to n$	$a_{\Lambda_b^0 n} = \frac{1}{\sqrt{6}} \frac{V_{ub}}{V_{us}} a_{\Sigma^+ p}$	0.0077
$\Lambda_b^0 \to \Lambda$	$a_{\Lambda_b^0 \Lambda} = -\frac{1}{6} V_{ub} a_{\Sigma^+ p}$	$-0.000\,72$
$\Xi_b^{\prime 0} \to \Xi_c^0$	$a_{\Xi_b^{\prime 0} \Xi_c^0} = -\frac{1}{\sqrt{12}} \frac{V_{cb}}{V_{us}} a_{\Sigma^+ p}$	-0.0641

TABLE III. Decay rates of Λ_b baryon in units of 10^{-15} GeV. Mannel, Roberts, and Ryzak, Phys. Lett. B **259**, 485 (1991).

Decay	Decay rate (Pole model) PC mode only	Decay rate (factorization*) PV + PC
Cabibbo allowed		
$\Lambda_b^0 \to \Lambda_c \pi^-$	0.22	2.55
$\Lambda_b^0 \to \Sigma_c^+ \pi^-$	1.09	0 in HQET
$\Lambda_b^0 \to \Lambda_c^+ D_s^-$	6.51×10^{-8}	12.80
$\Xi_b^- \to \Xi_c^0 \pi^-$	0.192	4.21
$\Xi_b'^- \to \Xi_c'^0 \pi^-$	0.192	4.21
$\Xi_b'^- \to \Xi_c^0 \pi^-$	0.575	0 in HQET
$\Xi_b^- \to \Xi_c'^0 \pi^-$	0.064	0 in HQET
Cabibbo suppressed		
$\Lambda_b^0 \to \Lambda_c^+ K^-$	2.00×10^{-3}	0.20
$\Lambda_b^0 \to \Sigma_c^+ K^-$	6.81×10^{-4}	0 in HQET
$\Lambda_b^0 \to \Lambda_c^+ D^-$	2.05×10^{-4}	0.55

For the decay mode $\Lambda_b \to \Lambda_c + \pi^-$, the decay rate for the parity-conserving mode is not negligible compared to the contribution from the factorization term [13]. However, in some decay modes, particularly those in which heavy meson is emitted, the pole contribution turns out to be very small compared with that of the factorization.

III. RESULTS AND DISCUSSION

The pole contribution to the decay rate of the Λ_b decaying into a charm baryon and a pseudoscalar meson does not seem negligible compared to the contribution of the factorization term in some cases, and so cannot be ignored and constitutes a significant branching ratio. The results are tabulated in Table III. In some cases, however, it is much smaller than the factorization contribution. It has been observed [14] that if the strong couplings are mass independent, the pole contribution will be small for b-baryon decays. We find here that the mass dependence of strong-coupling constants plays an important role in deciding the contribution of the pole terms. The pole terms seem to be important only for the modes when the light pseudoscalarlike pion is emitted. For the modes where heavier mesons are emitted, pole terms make negligible contributions. The measurements on decays of the b baryon will certainly throw light on the mechanism of these decays.

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