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Charmless Two-body Baryonic B Decays

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We study charmless two-body baryonic B decays in a diagramatic approach. Relations on decay amplitudes are obtained. In general there are more than one tree and more than one penguin amplitudes. The number of independent amplitudes can be reduced in the large m_B limit. It leads to more predictive results. Some prominent modes for experimental searches are pointed out.

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Baryonic modes in B decays are emerging [1, 2]. Several charmless three-body baryonic modes having rates of order 10^{-6} are observed [1]. On the other hand, so far, only upper limits are given for charmless two-body baryonic modes [1],

$$\mathscr{B}(\overline{B}^0 \to p\overline{p}) < 2.7\times 10^{-7}, \quad \mathscr{B}(\overline{B}^0 \to \Lambda\overline{\Lambda}) < 6.9\times 10^{-7}, \quad \mathscr{B}(B^- \to \Lambda\overline{p}) < 4.9\times 10^{-7}. \quad (1)$$

A simple scaling of $|V_{ub}/V_{cb}|^2$ on the $\overline{B}^0 \to \Lambda_c^+\overline{p}$ decay rate hints at a $\sim 10^{-7}$ rate for the charmless case [1]. The smallness of two-body rates can be understood by using an energy release argument [3]. The two-body baryonic decays are in general non-factorizable. In [4], a quark diagram approach was used to study charmless two-body baryonic B decays. This approach was developed and applied to the study of the two-body mesonic decays [5]. It is closely related to the SU(3) flavor symmetry. Note that it does not rely on any factorization assumption.

For the $b \to u\bar{u}d$ and $b \to q\bar{q}d$ processes, the tree ($\mathscr{O}_T$) and penguin ($\mathscr{O}_P$) operators respectively have the following flavor quantum numbers

$$\mathscr{O}_T \sim (b\overline{u})(u\overline{d}) = H^{ik}_j(b\overline{q}_i)(q^j\overline{q}_k), \quad \mathscr{O}_P \sim (b\overline{q}_i)(q^i\overline{d}) = H^k(b\overline{q}_i)(q^i\overline{q}_k), \quad (2)$$

with $H^{12}_1 = 1 = H^2$, otherwise $H^{ik}_j = H^k = 0$. The flavor structures of $|\Delta S| = 1$ tree and penguin operators can be obtained by replacing d to s and $H^{12}_1 = 1 = H^2$ to $H^{13}_1 = 1 = H^3$ in the above expression. For B to decuplet anti-decuplet decay, we use

$$q_i q_k q_l \to \overline{\mathscr{D}}_{ikl}, \qquad \bar{q}^l\bar{q}^j\bar{q}^m \to \mathscr{D}^{ljm}, \quad (3)$$

to match the $q_iq_kq_l$, $\bar{q}^l\bar{q}^j\bar{q}^m$ flavor contents of final state octet baryons (as shown in Fig. 1). While for octet baryons, we note that the $\mathscr{B}^j_k$ has a flavor structure $q^jq^aq^b\varepsilon_{abk} - \frac{1}{3}\delta^j_k q^cq^aq^b\,\varepsilon_{abc}$ and

$$q_iq_kq_l \to \varepsilon_{ika}\overline{\mathscr{B}}^a_l,\ \varepsilon_{ial}\overline{\mathscr{B}}^a_k,\ \varepsilon_{akl}\overline{\mathscr{B}}^a_i, \quad \bar{q}^l\bar{q}^j\bar{q}^m \to \varepsilon^{ljb}\mathscr{B}^m_b,\ \varepsilon^{lbm}\mathscr{B}^j_b,\ \varepsilon^{bjm}\mathscr{B}^l_b, \quad (4)$$

are used as the corresponding fields in $H_{\rm eff}$. In fact, not all terms in the above equation are independent. They are constrained by $\varepsilon_{ika}\overline{\mathscr{B}}^a_l + \varepsilon_{ial}\overline{\mathscr{B}}^a_k + \varepsilon_{akl}\overline{\mathscr{B}}^a_i = 0 = \varepsilon^{ljb}\mathscr{B}^m_b + \varepsilon^{lbm}\mathscr{B}^j_b + \varepsilon^{bjm}\mathscr{B}^l_b$. Hence for each of the $q_iq_kq_l$ and $\bar{q}^l\bar{q}^j\bar{q}^m$ configuration we only need two independent terms.

Using the above flavor flow analysis in $\overline{B} \to \mathscr{D}\overline{\mathscr{D}}$, $\mathscr{B}\overline{\mathscr{D}}$, $\mathscr{D}\overline{\mathscr{B}}$ and $\mathscr{B}\overline{\mathscr{B}}$ decays, we have [4]

$$\begin{aligned} H_{\rm eff} &= 6\,T_{\mathscr{D}\overline{\mathscr{D}}}\overline{B}_m H^{ik}_j \overline{\mathscr{D}}_{ikl}\mathscr{D}^{ljm} + 6\,P_{\mathscr{D}\overline{\mathscr{D}}}\overline{B}_m H^k \overline{\mathscr{D}}_{kil}\mathscr{D}^{lim}, \quad (5)\\ H_{\rm eff} &= -\sqrt{6}\,T_{1\mathscr{B}\overline{\mathscr{D}}}\overline{B}_m H^{ik}_j\varepsilon_{ika}\overline{\mathscr{B}}^a_l\mathscr{D}^{ljm} - \sqrt{6}\,T_{2\mathscr{B}\overline{\mathscr{D}}}\overline{B}_m H^{ik}_j\varepsilon_{akl}\overline{\mathscr{B}}^a_i\mathscr{D}^{ljm} - \sqrt{6}P_{\mathscr{B}\overline{\mathscr{D}}}\overline{B}_m H^k\varepsilon_{kia}\overline{\mathscr{B}}^a_l\mathscr{D}^{lim}, \end{aligned}$$

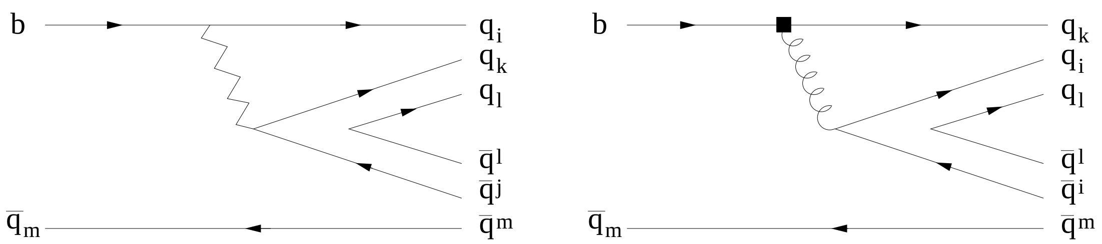

Figure 1: Pictorial representation Pictorial representation (from left to right) of (a) T (tree) and (b) P (penguin) amplitudes in $\overline{B}$ to baryon pair decays..

Table 1: Decay rates for $\Delta S=0$ tree-dominated modes (top) and for $|\Delta S|=1$ penguin-dominated modes (bottom). For tree-dominated modes, we consider only tree amplitude contribution with rates normalized to $\mathscr{B}(\overline{B}^0\to p\overline{p})$, which is taken to be 1×10^{-7}. For the penguin-dominated mode, we consider only penguin amplitude contribution with rates normalized to $\mathscr{B}(B^-\to\Lambda\overline{p})$, which is taken to be 1×10^{-7}. For comparison, results from pole model [6], diquark mode [7] and sum rule [8] calculations are shown in parentheses.

Mode	$\mathscr{B}(10^{-7})$		Mode	$\mathscr{B}(10^{-7})$		Mode	$\mathscr{B}(10^{-7})$
$\overline{B}^0\to p\overline{p}$	1	(1.1, 0.8, 1)	$B^-\to n\overline{p}$	1.09	(5.0,, 0, 0.6)	$\overline{B}^0_s\to p\overline{\Sigma^+}$	0.96
$n\overline{n}$	4.00	(1.2, 0.8, 0.3)	$\Sigma^0\overline{\Sigma^+}$	1.99		$n\overline{\Lambda}$	1.46
$\Lambda\overline{\Lambda}$	0	(0,0.4,–)	$p\overline{\Delta^{++}}$	6.19	(14, 0.6, 0.3)	$n\overline{\Sigma^0}$	0.48
$\Sigma^0\overline{\Lambda}$	2.79		$n\overline{\Delta^+}$	2.06	(4.6, 0.7, –)	$\Sigma^0\overline{\Xi^0}$	7.17
$\Sigma^0\overline{\Sigma^0}$	0.91		$\Sigma^0\overline{\Sigma^{*+}}$	3.81		$p\overline{\Sigma^{*+}}$	1.85
$p\overline{\Delta^+}$	1.90	(4.3, 0.3, 0.1)	$\Delta^0\overline{p}$	2.06		$n\overline{\Sigma^{*0}}$	0.92
$n\overline{\Delta^0}$	1.90	(4.3, 0.3, –)	$\Sigma^{*0}\overline{\Sigma^+}$	0.95		$\Sigma^0\overline{\Xi^{*0}}$	3.40
$\Sigma^0\overline{\Sigma^{*0}}$	1.75		$\Delta^+\overline{\Delta^{++}}$	11.72		$\Delta^+\overline{\Sigma^+}$	1.83
$\Delta^+\overline{p}$	1.90		$\Delta^0\overline{\Delta^+}$	3.91		$\Delta^0\overline{\Lambda}$	2.78
$\Delta^0\overline{n}$	7.60		$\Sigma^{*0}\overline{\Sigma^{*+}}$	1.82		$\Delta^0\overline{\Sigma^0}$	0.91
$\Sigma^{*0}\overline{\Lambda}$	1.34					$\Sigma^{*0}\overline{\Xi^0}$	3.44
$\Sigma^{*0}\overline{\Sigma^0}$	0.44					$\Delta^+\overline{\Sigma^{*+}}$	3.50
$\Delta^+\overline{\Delta^+}$	3.60					$\Delta^0\overline{\Sigma^{*0}}$	1.75
$\Delta^0\overline{\Delta^0}$	3.60					$\Sigma^{*0}\overline{\Xi^{*0}}$	1.63
$\Sigma^{*0}\overline{\Sigma^{*0}}$	0.84						
Mode	$\mathscr{B}(10^{-7})$		Mode	$\mathscr{B}(10^{-7})$		Mode	$\mathscr{B}(10^{-7})$
$B^-\to\Lambda\overline{p}$	1	(2.2, 0.2, <3.8)	$\overline{B}^0\to\Sigma^+\overline{p}$	0.07	(0.2, 0.9, 7.5)	$\overline{B}^0_s\to\Sigma^+\overline{\Sigma^+}$	0.06
$\Sigma^0\overline{p}$	0.04	(0.6, 0.2,, 3.8)	$\Lambda\overline{n}$	0.92	(2.1, 0.2,–)	$\Lambda\overline{\Lambda}$	0.60
$\Xi^0\overline{\Sigma^+}$	1.70		$\Sigma^0\overline{n}$	0.03	(–, 0.2, –)	$\Sigma^0\overline{\Sigma^0}$	0.06
$\Sigma^0\overline{\Delta^+}$	0.28	(–, 0.1, –)	$\Xi^0\overline{\Sigma^0}$	0.78		$\Xi^0\overline{\Xi^0}$	0.98
$\Xi^0\overline{\Sigma^{*+}}$	0.13		$\Sigma^0\overline{\Delta^0}$	0.26	(–, 0.2, –)	$\Sigma^+\overline{\Sigma^{*+}}$	0.12
$\Sigma^+\overline{\Delta^{++}}$	0.42	(2.0, 1.1, 7.5)	$\Xi^0\overline{\Sigma^{*0}}$	0.06		$\Sigma^0\overline{\Sigma^{*0}}$	0.12
$\Sigma^{*0}\overline{p}$	0.07		$\Sigma^+\overline{\Delta^+}$	0.13	(0.6, 0.6, 7.5)	$\Xi^0\overline{\Xi^{*0}}$	0.12
$\Xi^{*0}\overline{\Sigma^+}$	0.13		$\Sigma^{*0}\overline{n}$	0.06		$\Sigma^{*0}\overline{\Sigma^0}$	0.12
$\Sigma^{*0}\overline{\Delta^+}$	0.53		$\Sigma^{*+}\overline{p}$	0.13		$\Xi^{*0}\overline{\Xi^0}$	0.12
$\Sigma^{*+}\overline{\Delta^{++}}$	0.80		$\Xi^{*0}\overline{\Lambda}$	0.20		$\Sigma^{*+}\overline{\Sigma^+}$	0.12
$\Xi^{*0}\overline{\Sigma^{*+}}$	0.98		$\Xi^{*0}\overline{\Sigma^0}$	0.06		$\Xi^{*0}\overline{\Xi^{*0}}$	0.88
			$\Sigma^{*0}\overline{\Delta^0}$	0.49		$\Sigma^{*0}\overline{\Sigma^{*0}}$	0.24
			$\Sigma^{*+}\overline{\Delta^+}$	0.24		$\Sigma^{*+}\overline{\Sigma^{*+}}$	0.24
			$\Xi^{*0}\overline{\Sigma^{*0}}$	0.45			

$$
\begin{aligned}
H_{\rm eff} &= -\sqrt{6}\,T_{1\mathscr{D}\overline{\mathscr{B}}}\overline{B}_m H^{ik}_j\overline{\mathscr{D}}_{ikl}\varepsilon^{ljb}\mathscr{B}^m_b-\sqrt{6}\,T_{2\mathscr{D}\overline{\mathscr{B}}}\overline{B}_m H^{ik}_j\overline{\mathscr{D}}_{ikl}\varepsilon^{bjm}\mathscr{B}^l_b+\sqrt{6}P_{\mathscr{D}\overline{\mathscr{B}}}\overline{B}_m H^k\overline{\mathscr{D}}_{kil}\varepsilon^{bim}\mathscr{B}^l_b,\\
H_{\rm eff} &= T_{1\mathscr{B}\overline{\mathscr{B}}}\overline{B}_m H^{ik}_j\varepsilon_{ika}\overline{\mathscr{B}}^a_l\varepsilon^{ljb}\mathscr{B}^m_b+T_{2\mathscr{B}\overline{\mathscr{B}}}\overline{B}_m H^{ik}_j\varepsilon_{ika}\overline{\mathscr{B}}^a_l\varepsilon^{bjm}\mathscr{B}^l_b+T_{3\mathscr{B}\overline{\mathscr{B}}}\overline{B}_m H^{ik}_j\varepsilon_{akl}\overline{\mathscr{B}}^a_i\varepsilon^{ljb}\mathscr{B}^m_b\\
&\quad+T_{4\mathscr{B}\overline{\mathscr{B}}}\overline{B}_m H^{ik}_j\varepsilon_{akl}\overline{\mathscr{B}}^a_i\varepsilon^{bjm}\mathscr{B}^l_b-5P_{1\mathscr{B}\overline{\mathscr{B}}}\overline{B}_m H^k\varepsilon_{kia}\overline{\mathscr{B}}^a_l\varepsilon^{lib}\mathscr{B}^m_b-5P_{2\mathscr{B}\overline{\mathscr{B}}}\overline{B}_m H^k\varepsilon_{kia}\overline{\mathscr{B}}^a_l\varepsilon^{bim}\mathscr{B}^l_b,
\end{aligned}
$$

respectively, where only tree and penguin amplitudes are shown. In general there are more than one tree and more than one penguin amplitudes. In the large m_B limit, we have [4, 9]

$$T^{(\prime)}_{1\mathscr{B}\overline{\mathscr{B}}} = \frac{1}{2}T^{(\prime)}_{3\mathscr{B}\overline{\mathscr{B}}}, = -T^{(\prime)}_{2\mathscr{B}\overline{\mathscr{B}}} = -\frac{1}{2}T^{(\prime)}_{4\mathscr{B}\overline{\mathscr{B}}}, \quad P^{(\prime)}_{1\mathscr{B}\overline{\mathscr{B}}} = 5P^{(\prime)}_{2\mathscr{B}\overline{\mathscr{B}}},$$
$$T^{(\prime)} = T^{(\prime)}_{\mathscr{D}\overline{\mathscr{D}}} = T^{(\prime)}_{1\mathscr{B}\overline{\mathscr{D}}} = T^{(\prime)}_{1\mathscr{D}\overline{\mathscr{B}}} = T^{(\prime)}_{1\mathscr{B}\overline{\mathscr{B}}}, \quad P^{(\prime)} = P^{(\prime)}_{\mathscr{D}\overline{\mathscr{D}}} = P^{(\prime)}_{\mathscr{B}\overline{\mathscr{D}}} = P^{(\prime)}_{\mathscr{D}\overline{\mathscr{B}}} = P^{(\prime)}_{1\mathscr{B}\overline{\mathscr{B}}}, \tag{6}$$

and, consequently, only one tree and one penguin amplitudes are needed.

For $\Delta S = 0$ modes, we expect tree amplitudes to dominate.Their relative rates are estimated by neglecting penguin contribution. Rates are normalized to the $\overline{B}^0 \to p\overline{p}$ rate. A simple scaling of $|V_{ub}/V_{cb}|^2$ on the $\overline{B}^0 \to \Lambda_c^+\overline{p}$ decay rate hints at a 10^{-7} rate for the charmless case [1]. A pole model calculation also gives $\mathscr{B}(\overline{B}^0 \to p\overline{p}) = 1.1\times 10^{-7}$ [6]. For illustration, we take $\mathscr{B}(\overline{B}^0 \to p\overline{p}) = 1\times 10^{-7}$ as the reference rate for these tree-dominated decay rates. Similarly, for $|\Delta S| = 1$ modes, we use $\mathscr{B}(B^- \to \Lambda\overline{p}) = 1\times 10^{-7}$ for illustration. Results are summarized in Table 1.

Since the charmless two-body baryonic mode is not observed, in [4] some prominent modes are suggested to search for. In $\Delta S = 0$ processes, there are many promising modes. In addition of the $\overline{B}^0 \to p\overline{p}$ search, it is useful to search for $\overline{B}^0 \to \Sigma^0\overline{\Lambda}$ decay and $B^- \to \Delta^+\overline{\Delta^{++}}$, $p\overline{\Delta^{++}}$, $\Delta^0\overline{p}$ decays. For $|\Delta S| = 1$ processes, the $B^- \to \Lambda\overline{p}$ decay is still the best mode to search for. After the observation of any of the above mention modes, one should also search for other sub-dominated modes, such as $\overline{B}^0 \to p\overline{\Delta^+}$, $\Delta^+\overline{p}$, $\Sigma^0\overline{\Sigma^{*0}}$, $\Sigma^{*0}\overline{\Lambda}$, $\Xi^-\overline{\Sigma^-}$ and $B^- \to \Xi^-\overline{\Sigma^0}$, $\Sigma^{*+}\overline{\Delta^{++}}$. For the $\overline{B}_s$ case, one can search for the $p\overline{\Sigma^{(*)+}}$, $\Delta^0\overline{\Lambda}$, $\Xi^-\overline{\Xi^-}$ and $\Omega^-\overline{\Omega^-}$ decay modes. Although the above suggestions are obtained by considering the dominant contributions, we do not expect large modification of relative rate ratio in most cases. The tree-penguin interference effects can be included later after the appearance of data.

To conclude, we use a quark diagram approach to study charmless two-body baryonic decays. The topological amplitudes can be extracted from data. We further apply asymptotic relations to reduce the number of independent topological amplitudes and obtained predictive results. We have pointed out several promising modes to be added to the present experimental searching list. The discovery of any one of them should be followed by a bunch of other modes.

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