Remarks on the recently observed $B$ decays into $f_X(1300)K$ and $J/\psi K_X^*(1430)$

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Abstract

In light of the recent experimental results on decays $B^+ \to f_X(1300)K^+$ and $B^\pm(0) \to J/\psi K_X^{*\pm(0)}(1430)$ from Belle, we study the $B \to P(V)S$ type decays, $B^\pm(0) \to f_0(1370)K^{\pm(0)}$ and $B^\pm(0) \to J/\psi K_0^{*\pm(0)}(1430)$, in comparison with the $B \to P(V)T$ type decays, $B^\pm(0) \to f_2(1270)K^{\pm(0)}$ and $B^\pm(0) \to J/\psi K_2^{*\pm(0)}(1430)$. We calculate the BRs for these decays by using the form factors obtained in the ISGW2 model [the improved version of the original Isgur-Scora-Grinstein-Wise (ISGW) model], as well as the ISGW model for comparison. The ratios of $\mathcal{B}(B \to P(V)S)/\mathcal{B}(B \to P(V)T)$ are also presented.

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From $B$ factory experiments such as Belle and BaBar, a tremendous amount of experimental data on $B$ decays start to provide new bounds on previously known observables with an unprecedented precision as well as an opportunity to see very rare decay modes for the first time. Experimentally several scalar mesons ($S$) have been observed [1], such as the isospinor $K^*_0(1430)$, the isovectors $a_0(980)$ and $a_0(1450)$, the isoscalars $\sigma$ or $f_0(600)$, $f_0(1370)$, $f_0(1500)$, and heavier scalar mesons. Several tensor mesons ($T$) have been also observed [1]: for instance, the isovector $a_2(1320)$, the isoscalars $f_2(1270)$, $f_2(1525)$, $f_2(2010)$, $f_2(2300)$, $f_2(2340)$, $\chi_{c2}(1P)$, $\chi_{b2}(1P)$ and $\chi_{c2}(2P)$, and the isospinors $K^*_0(1430)$ and $D^*_0(2460)$. The measured branching ratios (BRs) for $B$ decays involving a pseudoscalar ($P$) or a vector ($V$), and a tensor meson in the final state provide only upper bounds [1]. In particular, the process $B \rightarrow K^*_2\gamma$ has been observed for the first time by the CLEO Collaboration with a branching ratio of $(1.66_{-0.66}^{+0.50} \pm 0.13) \times 10^{-5}$ [2], and by the Belle Collaboration with $B(B \rightarrow K^*_2\gamma) = (1.26 \pm 0.66 \pm 0.10) \times 10^{-5}$ [3].

Recently Belle reported the first observation of the decay $B^+ \rightarrow f_0(980)K^+$ [4], which is the first reported example of $B \rightarrow SP$ decay. The BR of $B(B^+ \rightarrow K^+\pi^+\pi^-) = (55.6 \pm 5.8 \pm 7.7) \times 10^{-6}$ was also measured for the first time by Belle [4]. However, the interpretation of possible states for a $\pi^+\pi^-$ invariant mass around 1300 MeV in the $K^+\pi^-\pi^+$ system remains unclear, even though two possible candidate states have been suggested: $f_0(1370)$ and $f_2(1270)$. The measured BR product for the $f_X(1300)K^+$ final state [4] is

$$B(B^+ \rightarrow f_X(1300)K^+) \times B(f_X(1300) \rightarrow \pi^+\pi^-) = (11.1_{-3.1}^{+3.4}_{-1.4+7.2}) \times 10^{-6}.$$  

At present, there exist some theoretical studies on the processes $B \rightarrow f_2(1270)K$ [5,6], but no theoretical information on the processes $B \rightarrow f_0(1370)K$ exists. Thus, it would be difficult to make clearer interpretation of the states for a $\pi^+\pi^-$ invariant mass around 1300 MeV in the $K^+\pi^-\pi^+$ system.

Another type of nonleptonic $B$ decays involving a scalar or a tensor meson has been very recently observed by Belle: $B^{\pm(0)} \rightarrow J/\psi K^{*\pm(0)}_X(1430)$, where $K^*_X(1430)$ is $K^*_0(1430)$ or $K^*_2(1430)$ [7]. This is also the first observation of $B \rightarrow VS$ decay. As the case of $B \rightarrow f_X(1300)K$, no theoretical information on the modes $B^{\pm(0)} \rightarrow J/\psi K^{*\pm(0)}_X(1430)$ exists, while some theoretical works on the modes $B^{\pm(0)} \rightarrow J/\psi K^{*\pm(0)}_0(1430)$ have been done [8–10]. Therefore, the interpretation of the state $K^*_X^{*\pm(0)}(1430)$ would be in difficulty and certain theoretical inputs would be necessary. In particular, the ratio of the BRs, $B(B \rightarrow J/\psi K^{*0}_0(1430))/B(B \rightarrow J/\psi K^{*2}_0(1430))$, would be very useful as such a theoretical input.

In light of the recent Belle results on $B^+ \rightarrow f_X(1300)K^+$ and $B^{\pm(0)} \rightarrow J/\psi K^{*\pm(0)}_X(1430)$, we study the $B \rightarrow PS$ and $B \rightarrow VS$ decays in comparison with the corresponding $B \rightarrow PT$ and $B \rightarrow VT$ decays. Our focus is on the particular processes $B^{\pm(0)} \rightarrow f_0(1370)K^{\pm(0)}$ and $B^{\pm(0)} \rightarrow J/\psi K^{*\pm(0)}_0(1430)$ in comparison with the processes $B^{\pm(0)} \rightarrow f_2(1270)K^{\pm(0)}$ and $B^{\pm(0)} \rightarrow J/\psi K^{*\pm(0)}_2(1430)$.

It is known [11] that in contrast to the vector and tensor mesons, the identification of the scalar mesons in experiment is difficult. Also theoretically the internal structure of most scalar mesons is not very clear [12,13]. Among light scalar mesons, $K^{*0}_0(1430)$ is the least controversial and its quark content is quite obvious. In contrast, the quark content of $f_0(1370)$ is relatively less clear: it is believed to be mainly $1\over \sqrt{2}(uu + dd)$, but the portion of its $ss$ component is unknown [14,15]. We set the quark content of $f_0(1370)$ as
\[ f_0(1370) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) \cos \phi_s + s\bar{s} \sin \phi_s , \]  

where \( \phi_s \) denotes the mixing angle of the scalar meson \( f_0(1370) \). Similarly, the quark content of the tensor meson \( f_2(1270) \) can be written as

\[ f_2(1270) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) \cos \phi_w + s\bar{s} \sin \phi_w , \]  

where the mixing angle \( \phi_w \) is given by \( \phi_w = \arctan(1/\sqrt{2}) - 28^\circ \approx 7^\circ \) [16,17].

The relevant \( \Delta B = 1 \) effective Hamiltonian for hadronic \( B \) decays can be written as

\[
H_{\text{eff}}^g = \frac{G_F}{\sqrt{2}} \left[ V_{ub} V_{ts}^* (c_1 O^q_{1u} + c_2 O^q_{2u}) + V_{cb} V_{ts}^* (c_1 O^q_{1c} + c_2 O^q_{2c}) - V_{tb} V_{ts}^* \sum_{i=3}^{10} c_i O^q_{i} \right] + \text{H.c.} ,
\]  

where \( O^q_i \)'s are defined as

- \( O^q_{1f} = \bar{q} \gamma_\mu L f \bar{f} \gamma^\mu L b \), \( O^q_{2f} = \bar{q}_a \gamma_\mu L f_\beta \bar{f}_\beta \gamma^\mu L b_\alpha \),
- \( O^q_{3(5)} = \bar{q} \gamma_\mu L b \sum_q \bar{q} \gamma_\mu L(R) q' \), \( O^q_{4(6)} = \bar{q}_a \gamma_\mu L b_\beta \sum_q \bar{q}_\beta \gamma_\mu L(R) q'_\alpha \),
- \( O^q_{7(8)} = \frac{3}{2} \bar{q} \gamma_\mu L b \sum_q e_q \bar{q} \gamma_\mu L(R) q', \) \( O^q_{9(10)} = \frac{3}{2} \bar{q}_a \gamma_\mu L b_\beta \sum_q e_q \bar{q}_\beta \gamma_\mu L(R) q'_\alpha \),

where \( L(R) = (1 \mp \gamma_5) \), \( f \) can be \( u \) or \( c \) quark, \( q \) can be \( d \) or \( s \) quark, and \( q' \) is summed over \( u, d, s, \) and \( c \) quarks. \( \alpha \) and \( \beta \) are the color indices. \( T^a \) is the SU(3) generator with the normalization \( \text{Tr}(T^a T^b) = \delta^{ab}/2 \). \( G^\mu_{ab} \) and \( F^{\mu\nu} \) are the gluon and photon field strength, and \( c_i \)'s are the Wilson coefficients (WCs). We use the improved effective WC's given in Ref. [18,19], where the renormalization scheme- and scale-dependence of the WC's are discussed and resolved. The regularization scale is taken to be \( \mu = m_b \) [20]. The operators \( O_1, O_2 \) are the tree level and QCD corrected operators, \( O_{3-6} \) are the gluon induced strong penguin operators, and finally \( O_{7-10} \) are the electroweak penguin operators due to \( \gamma \) and \( Z \) exchange, and the box diagrams at loop level.

To calculate the BR's of the interested decay processes, we adopt the generalized factorization framework. The hadronic matrix elements for \( B \to P(V)S \) and \( B \to P(V)T \) decays can be parameterized as

\[
\langle 0 | A^\mu | P \rangle = i f_P p_\mu^P , \quad \langle 0 | V^\mu | S \rangle = f_S p_\mu^S ,
\]

\[
\langle 0 | V^\mu | V \rangle = f_V m_v e^\mu ,
\]

\[
\langle S | A^\mu | B \rangle = F^B_{+\to S}(q^2)(p_B + p_S)^\mu + F^B_{-\to S}(q^2)(p_B - p_S)^\mu ,
\]

\[
\langle T | j^\mu | B \rangle = i h(q^2) e^{\mu\nu\rho\sigma} \epsilon^\nu_{\alpha\beta\gamma} p_\rho^P (p_B + p_T)_\sigma + k(q^2) e^{\mu\nu}(p_B)_\nu
+ \epsilon^*_{\alpha\beta\gamma} p_\beta^B b_\gamma(q^2)(p_B + p_T)^\mu + b_\gamma(q^2)(p_B - p_T)^\mu \]

where \( j^\mu = V^\mu - A^\mu \). \( V^\mu \) and \( A^\mu \) denote a vector and an axial-vector current, respectively. The \( f_M \) (\( M = P, S, V \)) denotes the decay constant of the relevant meson \( M \). The \( p_M^\mu \) (\( M = B, P, S, T \)) denotes the four-momentum of the relevant meson \( M \). Here \( \epsilon^\mu(\epsilon^{\mu\nu}) \) is the polarization vector (tensor) of the vector (tensor) meson. The \( F^B_{+\to S}(q^2) \) are the form factors.
for the $B \to S$ transition, and $h(q^2)$, $k(q^2)$, and $b_{\pm}(q^2)$ are the form factors for the $B \to T$ transition, which are calculated at $q^2$ ($q_{B}^{\mu} \equiv p_{B}^{\mu} - p_{S(T)}^{\mu}$). The form factors $F_{\pm}^{B \to S}$, $h$, $k$, $b$, contain nonperturbative nature of the $B \to S$ and $B \to T$ transitions, and in general they are functions of the momentum transfer $q^2 \equiv (p_B - p_{S(T)})^2$.

Note that $\langle 0|V^\mu|f_0 \rangle = 0$, since the decay constants of neutral scalars must vanish (i.e., $f_{f_0} = 0$) owing to charge conjugation invariance or conservation of vector current [21]. The decay constant of $K_{0}^{+}$ is not zero, but suppressed: for example, from the finite-energy sum rules [22], $f_{K_{0}^{+}} = 42$ MeV. For tensor mesons, the following relation holds:

$$\langle 0|j^{\mu}|T \rangle = p_{\nu}e^{\mu\nu}(p_T, \lambda) + p_B^{\mu}\epsilon^{\nu}(p_T, \lambda) = 0.$$  \hspace{1cm} (10)

Thus, there are no amplitudes proportional to $f_T(f_{f_0}) \times [\text{form factor for } B \to P(V)]$. Using the above parameterizations, the decay amplitudes for $B \to P(V)f_0$ and $B \to P(V)T$ [8,23] are

$$\mathcal{A}(B \to P f_0) \sim F_{+}^{B \to f_0}(q^2), \quad \mathcal{A}(B \to V f_0) \sim (\epsilon_{\mu}p_B^{\mu})F_{+}^{B \to f_0}(q^2),$$

$$\mathcal{A}(B \to PT) \sim F^{B \to T}(q^2), \quad \mathcal{A}(B \to VT) \sim \epsilon^{*\alpha\beta}F_{\alpha\beta}^{B \to T}(q^2),$$

where

$$F^{B \to T}(q^2) = k(q^2) + (m_B^2 - m_T^2)b_{+}(q^2) + m_T^2b_{-}(q^2),$$

$$F_{\alpha\beta}^{B \to T}(q^2) = \epsilon_{\mu}^{\nu}(p_B + p_T)\left[ih(q^2) \cdot e^{\mu\nu\rho\sigma}g_{\alpha\nu}(p_V)p_{\beta}(p_V) + k(q^2) \cdot \delta_{\alpha}^{\mu}\delta_{\beta}^{\nu} + b_{+}(q^2) \cdot (p_V)_{\alpha}(p_V)_{\beta}g^{\mu\nu}\right].$$  \hspace{1cm} (12)

The definition of $F_{\pm}^{B \to f_0}$ is given in Eq. (8). In passing, we note that in factorization the decay amplitude of $B \to J/\psi K_{0}^{*}$ has no term proportional to $f_{K_{0}^{*}}$, so it has the same structure as $\mathcal{A}(B \to V f_0)$: i.e., $\mathcal{A}(B \to J/\psi K_{0}^{*}) \sim (\epsilon_{\mu}p_B^{\mu})F_{+}^{B \to K_{0}^{*}}(q^2)$, where $\epsilon_{\mu}$ is the polarization vector of $J/\psi$.

As seen in Eq. (11), the decay amplitudes (and subsequently the BRs) are heavily dependent on the hadronic form factors which are model-dependent. To compute the $B \to S$ and $B \to T$ form factors, we use the ISGW2 model [24] which is the improved version of the nonrelativistic quark model of Isgur, Scora, Grinstein and Wise (ISGW) [25]. For comparison, we also compute the form factors using the original ISGW model. A characteristic feature of the form factors given in the original ISGW model is that values of the form factors decrease exponentially as a function of $(q_{m}^2 - q^2)$, where $q^2 \equiv (p_B - p_{S(T)})^2$ is the momentum transfer and $q_{m}^2 \equiv (m_B - m_{S(T)})^2$ is the maximum possible momentum transfer in the $B$ meson rest frame for a $B \to S(T)$ transition. This feature leads to the unreasonably small form factors at $q^2 = 0$, so the form factors are sometimes calculated at the maximum momentum transfer $q_{m}^2$, assuming that in the relevant transitions the momentum transfer $(q^2)$ is close to the maximum momentum transfer $(q_{m}^2)$. The ISGW model has been improved to the ISGW2 model in which the form factors have a more realistic behavior at large $(q_{m}^2 - q^2)$ by making the replacement of the exponentially decreasing term to a certain polynomial term [24].

Now we consider the decay processes $B^{\pm}(0) \to J/\psi K_{0}^{*+}(1430)$ and $B^{\pm}(0) \to f_0(1370)K^{\pm}(0)$ in comparison with $B^{\pm}(0) \to J/\psi K_{2}^{*+}(1430)$ and $B^{\pm}(0) \to f_2(1270)K^{\pm}(0)$. The relevant decay amplitudes are given by
\[ A(B^+(0) \rightarrow J/\psi K^{*+}_0(1430)) = -\frac{G_F}{\sqrt{2}} 2 m_{J/\psi} f_{J/\psi} (\varepsilon^* \cdot p_B) F_{+}^{B \rightarrow K^{*+}_0(0)} \]
\[ \times [V_{cs}^* V_{cs} a_2 - V_{tb}^* V_{ts} (a_3 + a_5 + a_7 + a_9)], \]
\[ A(B^+(0) \rightarrow J/\psi K^{*+}_2(1430)) = -\frac{G_F}{\sqrt{2}} m_{J/\psi} f_{J/\psi} \varepsilon^{\alpha \beta} F_{+}^{B \rightarrow K^{*+}_2(0)} \]
\[ \times [V_{cs}^* V_{cs} a_2 - V_{tb}^* V_{ts} (a_3 + a_5 + a_7 + a_9)], \]
\[ A(B^+ \rightarrow f_0(1370) K^+) = -i \frac{G_F}{2} \cos \phi_s (m_B^2 - m_{f_0}^2) f_{K} F_{+}^{B \rightarrow f_0} \]
\[ \times \{ V_{ub}^* V_{ua} a_1 - V_{tb}^* V_{ts} [a_4 + a_{10} - 2(a_6 + a_8) X_{su}] \}, \]
\[ A(B^0 \rightarrow f_0(1370) K^0) = i \frac{G_F}{2} \cos \phi_s (m_B^2 - m_{f_0}^2) f_{K} F_{+}^{B \rightarrow f_0} \]
\[ \times \{ V_{ub}^* V_{ua} a_1 - V_{tb}^* V_{ts} [a_4 + a_{10} - 2(a_6 + a_8) X_{su}] \}, \]
\[ A(B^+ \rightarrow f_2(1270) K^+) = -i \frac{G_F}{2} \cos \phi_s (\varepsilon^{\mu \nu}_B P_{BB}^\mu P_{B}^\nu) f_{K} F_{+}^{B \rightarrow f_2} \]
\[ \times \{ V_{ub}^* V_{ua} a_1 - V_{tb}^* V_{ts} [a_4 + a_{10} - 2(a_6 + a_8) X_{su}] \}, \]
\[ A(B^0 \rightarrow f_2(1270) K^0) = i \frac{G_F}{2} \cos \phi_s (\varepsilon^{\mu \nu}_B P_{BB}^\mu P_{B}^\nu) f_{K} F_{+}^{B \rightarrow f_2} \]
\[ \times \{ V_{ub}^* V_{ua} a_1 - V_{tb}^* V_{ts} [a_4 + a_{10} - 2(a_6 + a_8) X_{sd}] \}, \]

where
\[ X_{sq} = \frac{m_K^2}{(m_b + m_q)(m_s + m_q)} \quad (q = u, d). \]

Here the effective coefficients are defined as \( a_i = c_i^{eff} + \xi c_{i+1}^{eff} (i = odd) \) and \( a_i = c_i^{eff} + \xi c_{i-1}^{eff} (i = even) \) with the effective WC’s \( c^{eff} \) at the scale \( m_b \) [20,26], and by treating \( \xi \equiv 1/N_c \) (\( N_c \) is the effective number of colors) as an adjustable parameter. The terms with \( F_{+}^{B \rightarrow S} \) and \( b_+ \) are neglected because they give negligible contributions to the decay amplitudes due to the small mass factor. We have assumed that in \( B \rightarrow f_0(2) K \) the weak annihilation contribution can be neglected compared to the tree contribution.

From Eqs. (14) to (19), it is obvious that the ratios of the BRs, \( B(B \rightarrow J/\psi K^{*}_0(1430))/B(B \rightarrow J/\psi K^{*}_2(1430)) \) and \( B(B \rightarrow f_0(1370)K)/B(B \rightarrow f_2(1270)K) \), are independent of the parameter \( \xi \), though they are still sensitive to the form factors:

\[ \frac{B(B^{+}(0) \rightarrow J/\psi K^{*+}_0(1430))}{B(B^{+}(0) \rightarrow J/\psi K^{*+}_2(1430))} = \left| \frac{2(\varepsilon^* \cdot p_B) F_{+}^{B \rightarrow K^{*+}_0(0)}^2}{\varepsilon^{\alpha \beta} F_{+}^{B \rightarrow K^{*+}_2(0)}^2} \right|^2, \]

and
\[ \frac{B(B^{+}(0) \rightarrow f_0(1370)K^{+}(0))}{B(B^{+}(0) \rightarrow f_2(1270)K^{+}(0))} = \left| \frac{\cos \phi_s (m_B^2 - m_{f_0}^2) F_{+}^{B \rightarrow f_0}}{\cos \phi_s (\varepsilon^{\mu \nu}_B P_{BB}^\mu P_{B}^\nu) F_{+}^{B \rightarrow f_2}} \right|^2. \]

First, let us discuss magnitudes of the form factors in both models, the ISGW and its improved version ISGW2. In Table I, we show the values of the form factors \( F_{+}^{B \rightarrow K^{*}_0(0)} \).
and $\mathcal{F}_{B \to f_2}$ calculated in three cases: (i) at $q^2 = m_{J/\psi}^2$ or $m_K^2$ ($q^\mu \equiv p_B^\mu - p_{S(T)}^\mu$) in the ISGW model, (ii) at the maximum momentum transfer $q_m^2 \equiv (m_B - m_{S(T)})^2$ in the ISGW model, and (iii) at $q^2 = m_{J/\psi}^2$ or $m_K^2$ in the ISGW2 model. We note that in the ISGW model, $|\mathcal{F}_{B \to f_2(1270)}^B| = 0.19$ at $q_m^2$, while $|\mathcal{F}_{B \to f_2(1270)}^B| = 0.025$ at $q^2 = m_K^2$. The value of $|\mathcal{F}_{B \to f_2(1270)}^B|$ calculated at $q_m^2$ is 7.6 times larger than that calculated at $q^2 = m_K^2$. Thus, the BR of a relevant process (e.g., $B \to f_2(1270)K^\ast$) evaluated by using the former value of the form factor (evaluated at $q_m^2$) would be roughly 60 times larger than that obtained by using the latter value of the form factor (at $q^2 = m_K^2$). In contrast, in the ISGW2 model, $|\mathcal{F}_{B \to f_2(1270)}^B| = 0.078 at q^2 = m_K^2$ whose magnitude is in between that calculated at $m_K^2$ and that evaluated at $q_m^2$ in the ISGW model. This feature is quite common in $B \to PT$ and $B \to VT$ decays (See Table I of Ref. [8]). It is because as previously mentioned, a crucial improvement of the ISGW2 model is that the form factors in this model have a more realistic behavior at large $(q_m^2 - q^2)$, by changing the exponential factor of the form factors into a polynomial. Subsequently, the BR calculated in the ISGW2 model is usually in between that obtained at $q^2 = m_{P(V)}^2$ and that evaluated at zero recoil $q_m^2$ in the ISGW model (Table II).

However, we find that for the $B \to S$ form factors, the situation is somewhat different. From Table I, we see that

$$F_{+}^{B \to S}(in\ ISGW2) \lesssim F_{+}^{B \to S}(at\ q^2 = m_{P(V)}^2 \ in\ ISGW) < F_{+}^{B \to S}(at\ q_m^2 \ in\ ISGW),$$

for $S = K_0^{*+}(1430)$, $f_0(1370)$. Notice that the values of the form factors calculated in ISGW2 are similar to or even smaller than those obtained at $q^2 = m_{P(V)}^2$ in ISGW. This is not the case for the $B \to T$ form factors. The main reason why it happens for the $B \to S$ form factors is that in the ISGW2 model, there is an internal cancellation between two relevant terms in $F_{+}^{B \to S}$ [24], while in the ISGW model, no such cancellation appears [25]. Thus, in spite of its moderate behavior at large $(q_m^2 - q^2)$ in ISGW2, the form factor $F_{+}^{B \to S}(in\ ISGW2)$ becomes similar to or even smaller than $F_{+}^{B \to S}(at\ q^2 = m_{P(V)}^2 \ in\ ISGW)$. Consequently, the relevant BRs computed in ISGW2 are similar to or even smaller than those computed at $q^2 = m_{P(V)}^2$ in ISGW, and much smaller than those obtained at the maximum momentum transfer $q_m^2$ in ISGW (Table II and III). There is one more comment on $F_{+}^{B \to S}$ shown in Table I: for $B \to f_0(1370)K$, $(q_m^2 - q^2) = 15.0 \ GeV^2$, while for $B \to J/\psi K_0^{*+}(1430)$, $(q_m^2 - q^2) = 5.4 \ GeV^2$. Subsequently, in the ISGW model, the difference in $F_{+}^{B \to f_0(1370)}$ between two cases, at $q^2 = m_K^2$ and at $q_m^2$, is much larger than the corresponding difference in $F_{+}^{B \to K_0^{*+}(1430)}$.

Table II shows the BRs of $B \to J/\psi K_0^{*+}(1430)$ and $B \to J/\psi K_2^{*+}(1430)$, computed in the ISGW2 model. For comparison, the BRs computed in the ISGW model (using $a_2 = 0.26$) are also shown. In the table, the results are shown for three different values of the parameter $\xi$: $\xi = 0.1, 0.3, 0.5$. For comparison, the BRs are also calculated for $a_2 \equiv c_2^{eff} + \xi c_1^{eff} = 0.26$ whose values are obtained from a fit to $B \to PP$ and $B \to PV$ data [27]. The value of $a_2 = 0.26$ corresponds to $\xi = 0.54$. These decay modes are (color-suppressed) tree-dominant processes and their decay amplitudes are dominantly proportional to the effective coefficients $a_2$, as shown in Eqs. (14) and (15). Since the value of $a_2$ becomes very small for $\xi = 0.3$ due to a large cancellation between $c_2^{eff}$ and $\xi c_1^{eff}$, the BRs for $\xi = 0.3$ are much smaller than those for $\xi = 0.1$ or $\xi = 0.5$. From the table, we see that the BRs strongly depend.
on the relevant form factors. Using $a_2 = 0.26$, the BRs of $B^{+(0)} \to J/\psi K_0^{*+(0)}$ are about $7 \times 10^{-8}$ in the ISGW2 model, about $13 \times 10^{-8}$ at $q^2 = m_{f_J/\psi}^2$ and about $34 \times 10^{-8}$ at $q^2_m$ in the ISGW model. In contrast, the BRs of $B^{+(0)} \to J/\psi K_2^{*+(0)}$ are at least an order of magnitude larger than those of the corresponding $B^{+(0)} \to J/\psi K_0^{*+(0)}$ modes: using $a_2 = 0.26$, $B(B^{+(0)} \to J/\psi K_2^{*+(0)}) = (1 - 4) \times 10^{-6}$. Therefore, it is expected that the ratios of $B(J/\psi K_0^{*+(0)}(1430))/B(J/\psi K_2^{*+(0)}(1430))$ are very small: about $(2 - 10)\%$. These uncertainties arise only from the model-dependent form factors.

The BRs of $B^{+(0)} \to f_0(1370)K^{+(0)}$ and $B^{+(0)} \to f_2(1270)K^{+(0)}$ are presented in Table III. Unlike $B \to J/\psi K_0^{*+(0)}$ decays, these decays $B \to f_0(2)K$ are penguin-dominant processes. The charged modes $B^+ \to f_0(1370)K^+$ and $f_2(1270)K^+$ have tree contributions proportional to $a_1$ as well as dominant penguin contributions, while the neutral modes $B^0 \to f_0(1370)K^0$ and $f_2(1270)K^0$ are pure penguin processes, as shown in Eqs. (16)–(19). Because there appears a large cancellation between $a_1$ and $a_6$ in the penguin amplitudes of $B^{+(0)} \to f_0(1370)K^{+(0)}$ and $f_2(1270)K^{+(0)}$, the BRs of these modes become relatively small: $O(10^{-8}) - O(10^{-10})$ for $B^{+(0)} \to f_0(1370)K^{+(0)}$ and $O(10^{-7}) - O(10^{-9})$ for $B^{+(0)} \to f_2(1270)K^{+(0)}$. In particular, the BRs of the neutral modes are much smaller because these modes have only penguin contributions. In Table III, we have used $\cos \phi_s \approx 1$, which is a reasonable approximation, because the scalar meson $f_0(1370)$ is believed to be mainly composed of $u\bar{u}$ and $d\bar{d}$. In fact, even in case of assuming some sizable portion of the $s\bar{s}$ component of $f_0(1370)$, the BRs of $B \to f_0(1370)K$ do not change much: e.g., for $\phi_s = 18^\circ$ [14], these BRs change by only a few percent. The ratio of $B(f_0(1370)K^{+(0)})/B(f_2(1270)K^{+(0)})$ is independent of $\xi$ and shown to be 0.16 in the ISGW2 model. (But, in ISGW, the ratio is larger than 1.) The CP rate asymmetries $A_{CP}$ for $B \to f_0(2)K$ are shown to be very small in most cases: $0\% - 3\%$.

We note that for $B \to f_0(1370)K$ and $B \to f_2(1270)K$ decays, our prediction given in Table III is strongly model-dependent. Compared with the Belle data shown in Eq. (1), the BRs for $B \to f_0(1370)K$ decays predicted in the ISGW2 model seem to be very small. In particular, the BRs for $B \to f_0(2)K$ calculated at the maximum momentum transfer $q^2_m$ in ISGW model become about 40 (6) times larger than those calculated at $q^2 = m_K^2$ in the ISGW2 model. In this case (i.e., for $q^2_m$ in the ISGW model), both BRs for $B^+ \to f_0(1370)K^+$ and for $B^+ \to f_2(1270)K^+$ are an order of $10^{-6}$, which would be closer to the Belle data value. However, we would need more caution to seriously take these predicted values. Clearly more reliable values for the relevant form factors are called for from future studies.

To conclude, we have studied the $B \to P(V)S$ type decays, $f_0(1370)K$ and $B \to J/\psi K_0^{*+(0)}(1430)$, in comparison with the $B \to P(V)T$ type decays, $f_2(1270)K$ and $B \to J/\psi K_2^{*+(0)}(1430)$. To calculate the relevant hadronic form factors, we have used the ISGW2 model as well as the original ISGW model for comparison. The estimated BRs of these decays are sensitive to the model-dependent form factors. Using the ISGW2 model, the BRs are found to be $B(B^{+(0)} \to J/\psi K_0^{*+(0)}(1430)) \approx 7 \times 10^{-6}$ for $a_2 = 0.26$ and $B(B^{+(0)} \to J/\psi K_2^{*+(0)}(1430)) \approx 3.58(0.23) \times 10^{-8}$ for $\xi = 0.5$, while $B(B^{+(0)} \to J/\psi K_2^{*+(0)}(1430)) \approx 400 \times 10^{-6}$ for $a_2 = 0.26$ and $B(B^{+(0)} \to f_2(1270)K^+(K^0)) = 21.85(1.38) \times 10^{-8}$ for $\xi = 0.5$. The ratios of $B(P(V)S)/B(P(V)T)$ are independent of $\xi$, but model-dependent: in ISGW2, $B(J/\psi K_0^{*+(0)}(1430))/B(J/\psi K_2^{*+(0)}(1430)) \approx 2\%$ and $B(f_0(1370)K^{+(0)})/B(f_2(1270)K^{+(0)}) = 16\%$.  

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TABLE I. The form factors for the $B \to S$ and $B \to T$ transitions calculated at $q^2 = m_{J/\psi}^2$ (or $m_{K}^2$) and at the maximum momentum transfer $q_m^2 \equiv (m_B - m_{S(T)})^2$ in the ISGW model, and at $q^2 = m_{J/\psi}^2$ (or $m_{K}^2$) in the ISGW2 model, respectively. (Note that the definitions of $F_{+}^{B \to S}$ and $F_{+}^{B \to T}$ are different. See the text.)

| Form factor | ISGW | ISGW (at $q_m^2$) | ISGW2 |
|-------------|------|------------------|--------|
| $F_{+}^{B \to K_0^+ (1430)} (q^2 = m_{J/\psi}^2; q_m^2)$ | 0.38  | 0.61  | 0.29  |
| $F_{+}^{B \to f_0 (1370)} (q^2 = m_{K}^2; q_m^2)$ | 0.10  | 0.68  | 0.10  |
| $F_{+}^{B \to f_2 (1270)} (q^2 = m_{K}^2; q_m^2)$ | −0.025 | −0.19 | 0.078 |

TABLE II. The branching ratios (in $10^{-6}$) of $B \to J/\psi K_0^* (1430)$ and $B \to J/\psi K_0^* (1430)$, calculated at $q^2 = m_{J/\psi}^2$ in the ISGW2 model. For comparison, the branching ratios calculated in the original ISGW model (using $a_2 = 0.26$) are also shown in the square bracket for the following cases: (i) at $q^2 = m_{J/\psi}^2$ and (ii) at the maximum momentum transfer $q_m^2 \equiv (m_B - m_{K_0^* (2)})^2$. Both cases are shown in order, such as [(i); (ii)]. The ratios of $\mathcal{B}(B \to J/\psi K_0^* (1430))/\mathcal{B}(B \to J/\psi K_0^* (1430))$, which do not depend on $\xi$, are presented as well.

| Decay mode | $\mathcal{B}(10^{-6})[\xi = 0.1]$ | $\mathcal{B}(10^{-6})[\xi = 0.3]$ | $\mathcal{B}(10^{-6})[\xi = 0.5]$ | $\mathcal{B}(10^{-6})[a_2 = 0.26]$ |
|------------|----------------------------------|----------------------------------|----------------------------------|----------------------------------|
| $B^+ \to J/\psi K_0^{*+} (1430)$ | 7.19  | 0.04  | 5.23  | 7.42  |
| $B^0 \to J/\psi K_0^{*0} (1430)$ | 6.74  | 0.04  | 4.91  | 6.96  |
| $B^+ \to J/\psi K_2^{*+} (1430)$ | 384.14 | 2.07 | 279.70 | 396.49 |
| $B^0 \to J/\psi K_2^{*0} (1430)$ | 355.56 | 1.91 | 258.90 | 366.99 |

| $\mathcal{B}(J/\psi K_0^{*+} (1430))/\mathcal{B}(J/\psi K_2^{*+} (1430))$ | 0.019 |
| $\mathcal{B}(J/\psi K_0^{*0} (1430))/\mathcal{B}(J/\psi K_2^{*0} (1430))$ | 0.019 |
| $\mathcal{B}(J/\psi K_0^{*+} (1430))/\mathcal{B}(J/\psi K_2^{*0} (1430))$ | 0.092; 0.094 |
| $\mathcal{B}(J/\psi K_2^{*+} (1430))/\mathcal{B}(J/\psi K_2^{*0} (1430))$ | 0.04; 0.095 |
TABLE III. The branching ratios (in $10^{-8}$) of $B \to f_0(1370)K$ and $B \to f_2(1270)K$, calculated at $q^2 = m_K^2$ in the ISGW2 model. For comparison, the branching ratios calculated in the original ISGW model (for $\xi = 0.5$) are also shown in the square bracket for the following cases: (i) at $q^2 = m_K^2$ and (ii) at the maximum momentum transfer $q_m^2 \equiv (m_B - m_{f_0(2)})^2$. Both cases are shown in order, such as [(i); (ii)]. The ratios of $B(B \to f_0(1370)K)/B(B \to f_2(1270)K)$, which do not depend on $\xi$, are presented. The CP rate asymmetries $A_{CP}$ are shown as well.

| Decay mode | $B(10^{-8})[\xi = 0.1]$ | $B(10^{-8})[\xi = 0.3]$ | $B(10^{-8})[\xi = 0.5]$ | $A_{CP}$  |
|------------|------------------------|------------------------|------------------------|----------|
| $B^+ \to f_0(1370)K^+$ | 4.72 | 4.13 | 3.58 | 0.03 |
| $B^0 \to f_0(1370)K^0$ | 0.014 | 0.041 | 0.23 | [0.03; 0.03] |
| $B^+ \to f_2(1270)K^+$ | 28.84 | 25.22 | 21.85 | [0.03; 0.03] |
| $B^0 \to f_2(1270)K^0$ | 0.086 | 0.25 | 1.38 | [0; 0] |
| $B(f_0(1370)K^0)/(B(f_2(1270)K^0)$ | | | 0.16 | [1.53; 1.27] |