Branching ratios of $B_c$ Meson Decays into Tensor Meson in the Final State

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Abstract

Two-body hadronic weak decays of $B_c$ meson involving tensor meson in the final state are studied by using Isgur-Scora-Grinstein-Wise (ISGW II) model. Decay amplitudes are obtained using the factorization scheme in the Spectator Quark Model. Branching ratios for the charm changing and bottom changing decay modes are predicted.

Keywords: Nonleptonic decays, Bottom-charm decays, Non-Relativistic Quark Model.

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I. INTRODUCTION

Studies of the $B_c$ meson decays are important for several reasons. The $B_c$ meson discovered at Fermilab [1] is the only quark-antiquark bound system $(\bar{b}c)$ composed of heavy quarks $(b,c)$ with different flavors, and are thus flavor asymmetric. Recently, CDF Collaboration [2] announced an accurate determination of the $B_c$ meson mass and its life time. The investigation of the $B_c$ meson properties (mass spectrum, decay rates, etc.) is therefore of special interest compared to symmetric heavy quarkonium $(\bar{b}b,\bar{c}c)$ states. Also, $B_c$ meson attracts the interest of experimentalists for testing the predictions of perturbative QCD in the laboratory. The difference of quark flavors forbids the annihilation of $B_c$ meson into gluons. As a result, the pseudoscalar $(\bar{b}c)$ state is much more stable than the heavy quarkonium states, and decays only weakly. The decay processes of the $B_c$ meson can be broadly divided into two classes: involving the decay of $b$ quark, and that of $c$ quark, besides the annihilation of $b$ and $\bar{c}$. Preliminary estimates of the widths of some decay channels of $B_c$ have been made to show that the bound state effects may be significant in $B_c$ decays. Experimental study of the $B_c$ mesons are in plan for B-Physics both at the TEVATRON and Large Hadron Collider (LHC).

Earlier, there is a lot of work done in the semileptonic and nonleptonic [3-12] decays of the meson $B_c$ to a $s$-wave mesons. Also, the $p$-wave emitting decays of $B_c$ meson have been considered previously by other authors [13,14]. The present work consists the analysis of two-body hadronic weak decays of $B_c$ meson to pseudoscalar $(P)/$vector $(V)$ and tensor $(T)$ mesons in the final state employing the factorization hypothesis. The CKM-favored modes in charm changing and bottom changing decay modes are calculated using the non-relativistic quark model proposed by Isgur-Scora-Grinstein-Wise (ISGW) [15].

The present paper is organized as follows. Sec. II, includes meson spectroscopy. In Sec. III, methodology for $B_c \rightarrow PT/VT$ is discussed and the form factors involving $B_c \rightarrow T$ transition are calculated. Sec. IV deals with numerical results and discussions and summary and conclusions are given in the last section.

II. MESON SPECTROSCOPY

Experimentally [16], the tensor meson sixteen-plet comprises of an isovector $a_2(1.318)$, strange isospinor $K'_2(1.429)$, charm SU(3) triplet $D'_2(2.457)$, $D'_s(2.573)$ and three isoscalars $f_2(1.275)$, $f'_2(1.525)$ and $\chi_{c2}(3.555)$. These states behave well with respect to the quark model assignments, though the spin and parity of the charm isosinglet $D'_{s2}(2.573)$ remain to be confirmed. The numbers given within parentheses indicates the mass (in GeV units) of the respective mesons. $\chi_{c2}(3.555)$ is assumed to be pure $(cc\bar{c})$ state, and mixing of the isoscalar states is defined as:
\[ f_2(1.275) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) \cos \phi_r + (s\bar{s}) \sin \phi_r, \]
\[ f_2(1.525) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) \sin \phi_r - (s\bar{s}) \cos \phi_r, \]  
(1)

where \( \phi_r = \theta(\text{ideal}) - \theta_r(\text{physical}) \) and \( \theta_r(\text{physical}) = 27^\circ \).

For \( \eta \) and \( \eta' \) states of well established pseudoscalar sixteen-plet, we use

\[ \eta(0.547) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) \sin \phi_p - (s\bar{s}) \cos \phi_p, \]
\[ \eta'(0.958) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) \cos \phi_p + (s\bar{s}) \sin \phi_p, \]  
(2)

where \( \phi_p = \theta(\text{ideal}) - \theta_p(\text{physical}) \) and we take \( \theta_p(\text{physical}) = -15.4^\circ \) [16]. \( \eta_c \) is taken as

\[ \eta_c(2.979) = (c\bar{c}), \]  
(3)

Similarly, for \( \omega \) and \( \phi \) states of well established pseudoscalar sixteen-plet, we use

\[ \omega(0.783) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) \cos \phi_v + (s\bar{s}) \sin \phi_v, \]
\[ \phi(1.019) = \frac{1}{\sqrt{2}}(u\bar{u} + d\bar{d}) \sin \phi_v - (s\bar{s}) \cos \phi_v, \]  
(4)

where \( \phi_v = \theta(\text{ideal}) - \theta_v(\text{physical}) \) and we take \( \theta_v(\text{physical}) = 39^\circ \) [16]. \( J/\psi \) is taken as

\[ J/\psi(3.097) = (c\bar{c}). \]  
(5)

**III. METHODOLOGY**

**A. WEAK HAMILTONIAN**

To the lowest order in weak interaction, the non-leptonic Hamiltonian has the usual current \( \otimes \) current form

\[ J/\psi(3.097) = (c\bar{c}). \]  
(5)
\begin{equation}
H_w = \frac{G_F}{\sqrt{2}} J^\mu \not{J}_\mu + h.c.
\end{equation}

The weak current $J_\mu$ is given by

\begin{equation}
J_\mu = (\bar{u} \not{c} \not{t}) \gamma_\mu (1-\gamma_5) \begin{pmatrix} d' \\ s' \\ b' \end{pmatrix},
\end{equation}

where $d'$, $s'$ and $b'$ are mixture of the $d$, $s$ and $b$ quarks, as given by Cabibbo-Kobayashi-Maskawa (CKM) matrix [16].

**a) For bottom changing decays**

The QCD modified weak Hamiltonian [17] generating the $b$ quark decays in CKM enhanced modes ($\Delta b = 1$, $\Delta C = 1$, $\Delta S = 0$; $\Delta b = 1$, $\Delta C = 0$, $\Delta S = -1$) is given by

\begin{equation}
H_w^{\Delta b=1} = \frac{G_F}{\sqrt{2}} \left\{ V_{cb} V_{ub}^* \left[ c_1(\mu)(\bar{c}b)(\bar{d}u) + c_2(\mu)(\bar{c}u)(\bar{d}b) \right] + V_{cb} V_{cs}^* \left[ c_1(\mu)(\bar{c}b)(\bar{s}c) + c_2(\mu)(\bar{c}c)(\bar{s}b) \right] \right\},
\end{equation}

where $G_F$ is the Fermi constant and $V_{ij}$ are the CKM matrix elements, $c_1$ and $c_2$ are the standard perturbative QCD coefficients.

**b) For bottom conserving and charm changing decays**

In addition to the bottom changing decays, bottom conserving decay channel is also available for the $B_c$ meson, where the charm quark decays to an $s$ or $d$ quark. The weak Hamiltonian generating the $c$ quark decays in CKM enhanced mode ($\Delta b = 0$, $\Delta C = -1$, $\Delta S = -1$) is given by

\begin{equation}
H_w^{\Delta c=1} = \frac{G_F}{\sqrt{2}} V_{ud} V_{cs}^* \left[ c_1(\mu)(\bar{u}d)(\bar{s}c) + c_2(\mu)(\bar{u}c)(\bar{s}d) \right].
\end{equation}

One naively expects this channel to be suppressed kinematically due to the small phase space available. However, the kinematic suppression is well compensated by the CKM element $V_{cs}$, which is larger than $V_{cb}$ appearing for the bottom changing decays. In fact, we shall show later that bottom conserving decay modes are more prominent than the bottom changing ones.

By factorizing matrix elements of the four-quark operator contained in the effective Hamiltonian (8) and (9), one can distinguish three classes of decays [18]:
The first class contains those decays which can be generated from color singlet current and the decay amplitudes are proportional to $a_1$, where $a_1(\mu) = c_1(\mu) + \frac{1}{N_c} c_2(\mu)$, and $N_c$ is the number of colors.

Second classes of transitions consist of those decays which can be generated from neutral current. The decay amplitude in this class is proportional to $a_2$, i.e. for the color suppressed modes $a_2(\mu) = c_2(\mu) + \frac{1}{N_c} c_1(\mu)$.

The third class of decay modes can be generated from the interference of color singlet and color neutral currents i.e. the $a_1$ and $a_2$ amplitudes interfere.

Following the convention of large $N_c$ limit to fix QCD coefficients $a_1 = c_1$ and $a_2 = c_2$, where [18] $c_1$ and $c_2$ are fixed as:

$$c_1(\mu) = 1.26 \ , \ c_2(\mu) = -0.51 \text{ at } \mu = m_c^2,$$

$$c_1(\mu) = 1.12 \ , \ c_2(\mu) = -0.26 \text{ at } \mu = m_b^2. \quad (10)$$

### B. DECAY AMPLITUDES AND RATES

**a) $B_c \rightarrow PT$ Decay:**

The decay rate formula for $B_c \rightarrow PT$ decays is given by

$$\Gamma(B_c \rightarrow PT) = \left( \frac{m_{B_c}}{m_F} \right)^2 \left( \frac{p_c}{12 \pi m_F^2} \right)^2 |A(B_c \rightarrow PT)|^2,$$

where $p_c$ is the magnitude of the three-momentum of a final-state particle in the rest frame of $B_c$ meson and $m_F$ denotes the mass of the tensor meson.

The factorization scheme expresses the decay amplitude as the product of matrix elements of weak currents (up to the weak scale factor of $\frac{G_F}{\sqrt{2}} \times$ CKM elements $\times$ QCD factor) as

$$\langle PT | H_w | B_c \rangle \sim \langle P | J^\mu | 0 \rangle \langle T | J_\mu | B_c \rangle + \langle T | J^\mu | 0 \rangle \langle P | J_\mu | B_c \rangle,$$

(12)

However, the matrix element
\[ \langle T \mid J^\mu \mid 0 \rangle = 0, \quad (13) \]

because the trace of the polarization tensor \( \varepsilon^{\mu \nu} \) of the tensor meson \( T \) vanishes and the auxiliary condition holds, \( p_T^\mu \varepsilon^{\mu \nu} = 0 \). Thus, in the generalized factorization scheme, the decay amplitudes for \( B_c \to PT \) are considerably simple in comparison to the other two-body charmless decays of \( B \) mesons.

One can use the ISGW quark model [15] to analyze two-body decay processes \( B_c \to PT \) in the framework of generalized factorization, where the parameterizations of the hadronic matrix elements in \( B_c \to PT \) decays are described as:

\[
\langle P \mid J^\mu \mid 0 \rangle = -if_P k_\mu, \\
\langle T \mid J^\mu \mid B_c \rangle = i\hbar \varepsilon^{\mu \nu \lambda \rho} \varepsilon^{\nu \alpha \lambda \rho} p_{P \mu} (P_{B_c} + P_T)^\lambda (P_{B_c} - P_T)^\rho \\
+ k \varepsilon^{\nu \alpha \beta} P_{P \mu}^\nu + b_+ \varepsilon^{\nu \alpha \beta} P_{P \mu}^\nu (P_{B_c} + P_T)^\alpha + b_- (P_{B_c} - P_T)^\alpha, \quad (14)\]

where \( k_\mu = (P_{B_c} - P_T)_\mu \) and \( f_P \) denotes the decay constant of pseudoscalar mesons. \( P_{B_c} \) and \( P_T \) denotes the momentum of the \( B_c \) meson and the tensor meson, respectively. The ISGW model yields

\[
\langle PT \mid H_W \mid B_c \rangle = -if_p \varepsilon^{\nu \alpha \beta} P_{P \mu}^\nu (m_p^2 - m_T^2)(m_p^2), \quad (15)\]

where

\[ F^{B_c \to T}(m_p^2) \]

\( \varepsilon^{\nu \alpha \beta} \) is the symmetric and traceless tensor describing the polarization of tensor mesons. The argument, \( F^{B_c \to T} \), in the function means that the form factors \( k, b_+ \) and \( b_- \) should be evaluated at \( m_p^2 \).

Thus the decay amplitude, in general, have the following form

\[
A(B \to PT) = \frac{G_F}{\sqrt{2}} \times (\text{CKM factors} \times \text{QCD factors}) \times f_p F^{B_c \to T}(m_p^2). \quad (17)\]

b) \( B_c \to VT \) Decay:

The decay rate formula for \( B_c \to VT \) [19] is,
\[ \Gamma(B_c \rightarrow VT) = \frac{G_F^2}{48\pi m_{B_c} f_V^2} m_{V_f} \sum [\alpha |\bar{p}_V|^2 + \beta |\bar{p}_V|^2 + \gamma |\bar{p}_V|^2], \] (18)

where \( |p_V| \) is the magnitude of the three-momentum of the final-state particle \( V \) or \( T \) \((|p_V| = |p_T|)\) in the rest frame of \( B_c \) meson. \( \alpha, \beta \) and \( \gamma \), respectively, are quadratic functions of the form factors, are given by

\[ \begin{align*}
\alpha &= 8m_{B_c}^4 b_c^2, \\
\beta &= 2m_{B_c}^2 [6m_V^2 m_T^2 h^2 + 2(m_{B_c}^2 - m_V^2 - m_T^2) k b_c + k^2], \\
\gamma &= 5m_V^2 m_T^2 k^2.
\end{align*} \] (19)

Here also the decay amplitude can be expressed as the product of matrix elements of weak currents (up to the weak scale factor of \( \frac{G_F}{\sqrt{2}} \) × CKM elements × QCD factor):

\[ \langle VT | H_w | B_c \rangle \sim \langle V | J^\mu | 0 \rangle \langle T | J_\mu | B_c \rangle + \langle T | J^\mu | 0 \rangle \langle V | J_\mu | B_c \rangle. \] (20)

The hadronic matrix elements is:

\[ \langle V | J_\mu | 0 \rangle = \varepsilon_\mu^* m_V f_V, \] (21)

where \( f_V \) denotes the decay constant of the vector meson. Relations (14) and (21) yields

\[ \langle VT | H_w | B_c \rangle = m_V f_V F_{a_\mu \rightarrow T}^B (m_V^2). \] (22)

where

\[ F_{a_\mu \rightarrow T}^B = \varepsilon_\mu^* (P_{B_c} + P_T)_\rho [i \lambda^{\sigma \rho \sigma} (P_V)_\rho (P_T)_\sigma + k \delta_\sigma^\nu \delta_\rho^\sigma + b_+ (P_V)_\rho (P_T)_\sigma \delta_\mu^\sigma]. \] (23)

In the above expressions, \( \varepsilon_\mu^* \) denotes the polarization four-vector of \( V \). The form factors \( h, k, b_+ \) and \( b_- \) should be evaluated at \( m_V^2 \).

Finally,

\[ A(B \rightarrow VT) = \frac{G_F}{\sqrt{2}} \times (\text{CKM factors} \times \text{QCD factors}) \times m_V f_V \varepsilon_\mu^* F_{a_\mu \rightarrow T}^B (m_V^2). \] (24)
The required form factors $h$, $k$, $b_+$ and $b_-$ are calculated from the following expressions of ISGW II model [15]:

$$h = \frac{m_d}{2\sqrt{2m_H\beta_H}} \left(1 - \frac{m_d\beta_H^2}{2\mu m_T \beta_{H,T}^2}\right) F_{5}^{(h)},$$

$$k = \frac{m_d}{\sqrt{2\beta_H}} (1 + \tilde{\omega}) F_{3}^{(k)},$$

$$b_+ + b_- = \frac{m_d^2}{4\sqrt{2m_H\beta_H \beta_{H,T}}} \left(1 - \frac{m_d\beta_T^2}{2m_H \beta_{H,T}^2}\right) F_{5}^{(h,b_+),},$$

$$b_+ - b_- = -\frac{m_d}{\sqrt{2m_H\beta_H \beta_{H,T}}} \left(1 - \frac{m_d\beta_T^2}{2m_H \beta_{H,T}^2} + \frac{m_d}{4m_H \beta_{H,T}^2} \left(1 - \frac{m_d \beta_T^2}{2m_H \beta_{H,T}^2}\right) \right) F_{5}^{(h,b_-),}.$$

where

$$F_{5}^{(h)} = F_{5} \left(\frac{\bar{m}_H}{m_H}\right)^{\nu/2} \left(\frac{\bar{m}_T}{m_T}\right)^{\nu/2},$$

$$F_{5}^{(k)} = F_{5} \left(\frac{\bar{m}_H}{m_H}\right)^{\nu/2} \left(\frac{\bar{m}_T}{m_T}\right)^{\nu/2},$$

$$F_{5}^{(h,b_+),} = F_{5} \left(\frac{\bar{m}_H}{m_H}\right)^{\nu/2} \left(\frac{\bar{m}_T}{m_T}\right)^{\nu/2},$$

$$F_{5}^{(h,b_-),} = F_{5} \left(\frac{\bar{m}_H}{m_H}\right)^{\nu/2} \left(\frac{\bar{m}_T}{m_T}\right)^{\nu/2},$$

and

$$\tilde{\omega} - 1 = \frac{t_m - t}{2\bar{m}_H \bar{m}_T}. \quad (27)$$

The common scale factor is given by

$$F_{n} = \left(\frac{\bar{m}_T}{m_T}\right)^{3/2} \left(\frac{\beta_T \beta_{H,T}}{\beta_H^2}\right)^{3/2} \left[1 + \frac{1}{18} \chi^2 (t_m - t) \right]^{-3}, \quad (28)$$

where

$$\chi^2 = \frac{3}{4m_H m_q} + \frac{3 m_d^2}{2 \bar{m}_H \bar{m}_T \beta_{H,T}^2} + \frac{1}{\bar{m}_H \bar{m}_T} \left[\frac{16}{33 - 2n_f} \ln\left(\frac{\alpha_s(m_{OM})}{\alpha_s(m_q)}\right)\right]. \quad (29)$$
\[ \beta_{\rho,T}^2 = \frac{1}{2} \left( \beta_{\rho}^2 + \beta_{T}^2 \right), \]  

(30)

\( \bar{m} \) is the sum of the mesons constituent quark masses, \( \bar{m} \) is the hyperfine averaged physical masses, \( n_f \) is the number of active flavors, which is taken to be five in the present case, \( t_m = (m_{B_\rho} - m_{T})^2 \) is the maximum momentum transfer and

\[ \mu_s = \left( \frac{1}{m_q} + \frac{1}{m_b} \right)^{-1}, \]  

(31)

with \( m_q \) and \( m_d \) being the masses of the quark \( q_i \) and \( \bar{q}_2 \), respectively. Following ISGW II quark model values [15] of the quark masses (in GeV) are used:

\[ m_u = m_d = 0.33, \quad m_s = 0.55, \quad m_c = 1.82, \quad m_b = 5.20, \]  

(32)

and values of the parameter \( \beta \)'s for different \( s \)-wave and \( p \)-wave mesons as given in the Table I. The obtained the form factors describing \( B_c \rightarrow T \) transitions are given in Table II at \( q^2 = t_m \). It may be noted that \( B_c \rightarrow P/V \) form factors do not appear in the decay amplitudes given in Tables III and IV. However, in order to get an estimate of these form factors and the predictability of the model, one can compare the results of semileptonic weak decays for \( B_c \rightarrow P/V \) channels in ISGW II model [15] with the prediction of other models as shown in Table V, we find that the results are reasonably comparable with the other models.

IV. NUMERICAL RESULTS AND DISCUSSIONS

Sandwiching the weak Hamiltonian (8) and (9) between the initial and final states, we obtain the decay amplitudes of \( B_c \) meson for the various decay modes as given in the Tables III and IV. For numerical calculations, we use the following values of the decay constants (given in GeV units) of pseudoscalar mesons [8, 16] and vector mesons [17]:

\[ f_{\pi} = 0.131, \quad f_k = 0.160, \quad f_D = 0.223, \quad f_{D_s} = 0.294, \]  

\[ f_\eta = 0.133, \quad f_\eta = 0.126, \quad f_{\eta_c} = 0.400. \]  

(33)

and

\[ f_\rho = 0.221, \quad f_\rho = 0.220, \quad f_{D'} = 0.245, \quad f_{D_s} = 0.273, \]  

\[ f_\omega = 0.195, \quad f_\phi = 0.229, \quad f_{J/\psi} = 0.411. \]  

(34)
Finally, branching ratios of \( B_c \rightarrow PT \) meson decays in charm changing and bottom changing decay modes and branching ratios of \( B_c \rightarrow VT \) meson decays in bottom changing decay modes are calculated. The measurement of these decays would provide an additional test of the quark models used to compute the hadronic matrix elements. The results are given in Tables VI and VII for the various possible Cabibbo-favored decay modes and the observation are listed as follows:

I) For \( B_c \rightarrow PT \) meson decays (in Table VI):

   i) Dominant decays for bottom changing decay modes are, 
      \[ B(B_c^- \rightarrow D_s^- \chi_{c2}) = 3.2 \times 10^{-4} \] 
      and \( B(B_c^- \rightarrow \pi^- \chi_{c2}) = 2.0 \times 10^{-4} \), which seems to be at the reach of future experiments. The next order dominant decays are \( B(B_c^- \rightarrow K^- \chi_{c2}) = 1.5 \times 10^{-5} \), \( B(B_c^- \rightarrow \eta_D D_{s2}^-) = 1.4 \times 10^{-5} \) and \( B(B_c^- \rightarrow D^- \chi_{c2}) = 1.2 \times 10^{-5} \).

   ii) Branching ratio of decay, \( B(B_c^- \rightarrow \pi^- \chi_{c2}) = 2.0 \times 10^{-4} \), are comparable with the numerical value of the recent work [13].

   iii) Branching ratio of dominant decay for charm changing decay mode is, 
      \[ B(B_c^- \rightarrow \pi^+ \chi_{c2}') = 3.0 \times 10^{-4} \], which proceeds via \( b \) quark as an spectator, has a similar order of branching ratio than \( c \) quark spectator decays i.e. 
      \( B_c^- \rightarrow D_s \chi_{c2} / \pi^- \chi_{c2} \), although it is suppressed by phase space but favored by the CKM factor.

   iv) Among \( \Delta b = 1, \Delta C = 1, \Delta S = 0 \) mode, \( B_c^- \rightarrow K^0 K^- / \pi^0 a_2^- / \pi^- a_2^- / \pi^- f_2^- / \pi^- f_2' / \eta a_2^- / \eta' a_2^- / K^- f_2^- / \eta' f_2^- / D^- a_0^- / \eta a_2^- \) are forbidden in our analysis. However, these decays occur through the annihilation mechanism. Decay \( B_c^- \rightarrow D^- D_2^0 \) may also be generated through elastic final state interactions (FSIs).

   v) In case of \( \Delta b = 1, \Delta C = 0, \Delta S = -1 \) decay mode, \( B_c^- \rightarrow \bar{K}^0 D_2^- / D^- \bar{K}_2^0 / \bar{D}^0 K^- / D_s^* a_0^- / D_s^- f_2^- / D_s^- f_2'^- \) are forbidden. However, these decays occur through the annihilation mechanism. Decay \( B_c^- \rightarrow \bar{K}^0 D_2^- \) may also be generated through elastic final state interactions (FSIs).

II) For \( B_c \rightarrow VT \) meson decays (in Table VII):

   i) For Bottom changing decay modes, branching ratios of dominant mode are 
      \[ B(B_c^- \rightarrow D_s^- \chi_{c2}) = 8.8 \times 10^{-4} \] 
      and \( B(B_c^- \rightarrow \rho^- \chi_{c2}) = 2.4 \times 10^{-4} \). Branching ratio
of the decay $B_c^- \rightarrow \rho^- \chi_{c2}$ matches well with the value of Ref [14]. Branching ratio for next order dominant decay is $B(B_c^- \rightarrow J/\psi D_{s2}^-) = 9.6 \times 10^{-5}$. Note that the $b$ spectator decays do not appear as they are kinematically forbidden.

ii) In $\Delta b = 1, \Delta C = 1, \Delta S = 0$ mode, $B_c^- \rightarrow K^{*0} K_s^- / \rho^0 a_2^- / \rho^- a_2^0 / \rho^- f_2 / \rho^- f_2'$ / $\omega a_2^- / K^- K_s^0 / \phi a_2^- / D^- D_s^0 / J / \psi a_2^-$ are forbidden in the present analysis. However, like $B_c \rightarrow PT$ decays these may also occur through the annihilation mechanism. Decay $B_c^- \rightarrow D^- D_s^0$ may also be generated through elastic final state interactions (FSIs).

iii) Also, in $\Delta b = 1, \Delta C = 0, \Delta S = -1$ mode, $B_c^- \rightarrow \overline{K}^{*0} D_s^- / D^- \overline{K}_s^0 / D_s^- a_2^0 / \overline{D}^{*0} K^- / D_s^- f_2 / D_s^- f_2'$ are forbidden and occur through the annihilation mechanism. Decay $B_c^- \rightarrow \overline{K}^{*0} D_s^-$ may also be generated through elastic final state interactions (FSIs).

For the sake of comparison, the results of other works [13, 14] are given in the Tables VI and VII. C.H. Chang et al. [13] have calculated only the $c$ spectator decay modes using generalized instantaneous approximation, in which branching ratio of $B_c^- \rightarrow D_s^- \chi_{c2}$ decay is large as compare to the present value. In general, the present branching ratios of few decays are of the same order of magnitude as observed in [13,14] and in other cases branching ratios are larger as compared to [14]. Ivanov et al. [8] studied exclusive nonleptonic and semileptonic decays of the $B_c$ meson within a relativistic constituent quark model developed by them. In their recent work [8], they have calculated the nonleptonic decays with one of the final state being pure $c\overline{c}$. They predict $B(B_c^- \rightarrow \pi^- \chi_{c2})$ and $B(B_c^- \rightarrow \rho^- \chi_{c2})$ as $4.6 \times 10^{-4}$ and $1.2 \times 10^{-3}$ respectively, which are large as compare to present results. Similarly, in another recent work [5] the same decays have been quoted with the branching ratios ($B(B_c^- \rightarrow \pi^- \chi_{c2}) = 2.2 \times 10^{-4}$ and $B(B_c^- \rightarrow \rho^- \chi_{c2}) = 6.5 \times 10^{-4}$), that are of the same order of magnitude as the compared to present work. It has also been observed that the largest numerical values of branching ratios $B_c \rightarrow PT/VT$ are of the same order as those of some $B_c \rightarrow PP/PV/VV$ decay modes [4-12]. In $B$ meson decays, the experimental data favors constructive interference, in contrast to the charm meson sector, between the color favored and color suppressed diagrams, thereby yielding $a_1 = 1.10 \pm 0.08$ and $a_2 = 0.20 \pm 0.02$. Our results remain unaffected from interference of $a_i$ (color favored) and $a_i$ (color suppressed).
V. SUMMARY AND CONCLUSIONS

In this paper, the two-body hadronic weak decays of $B_c$ meson to pseudoscalar/vector and tensor mesons in charm changing as well as bottom changing decay modes, employing the ISGW II model, are studied. However, the charm changing decay modes ($b$ spectator) are kinematically forbidden in case of the decays involving one vector meson in the final state. Various form factors for $cB_T \rightarrow T$ transition are obtained using the Isgur-Scora-Grienstein-Wise (ISGW II) quark model. Consequently, branching ratios of $B_c \rightarrow PT$ and $B_c \rightarrow VT$ for various Cabibbo-favored decay modes are calculated. Conclusions are as follows.

i) Dominant decay modes for $B_c \rightarrow PT$ are $B(B_c^+ \rightarrow \pi^+ B_{12}^0) = 3.0 \times 10^{-4}$, $B(B_c^- \rightarrow D_s^- \chi_{c2}) = 3.2 \times 10^{-4}$ and $B(B_c^- \rightarrow \pi^- \chi_{c2}) = 2.0 \times 10^{-4}$. For $B_c \rightarrow VT$ decays, $B(B_c^- \rightarrow D_s^- \chi_{c2}) = 8.8 \times 10^{-4}$ and $B(B_c^- \rightarrow \rho^- \chi_{c2}) = 2.4 \times 10^{-4}$, are dominant decays. Branching ratios for these decays seem to be within the reach of current experiments. Observation of these processes in the $B_c$ experiments such as Belle, Babar, BTeV, LHC and so on will be crucial in testing the ISGW quark model as well as validity of the factorization scheme.

ii) In contrast to the charm meson sector, the experimental data of $B$ meson decays favor the constructive interference between color favored and color suppressed diagrams, giving $a_1 = 1.10 \pm 0.08$ and $a_2 = 0.20 \pm 0.02$. In the present analysis, the decay amplitude is proportional to only one QCD coefficient either $a_1$ (for color favored diagram) or $a_2$ (for color suppressed diagram), therefore these results remain unaffected from interference of $a_1$ and $a_2$.

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Table I. The values of parameter $\beta$ for $s$-wave and $p$-wave mesons in the ISGW II quark model

| Quark content | $u\bar{d}$ | $u\bar{s}$ | $s\bar{s}$ | $c\bar{u}$ | $c\bar{s}$ | $u\bar{b}$ | $s\bar{b}$ | $c\bar{c}$ | $b\bar{c}$ |
|---------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| $\beta_s$ (GeV) | 0.41   | 0.44    | 0.53    | 0.45    | 0.56    | 0.43    | 0.54    | 0.88    | 0.92    |
| $\beta_p$ (GeV) | 0.28   | 0.30   | 0.33   | 0.33   | 0.38   | 0.35   | 0.41  | 0.52   | 0.60   |

Table II. Form factors of $B_s \rightarrow T$ transition at $q^2 = t_m$ in the ISGW II quark model

| Modes | Transition | $h$   | $k$   | $b_s$ | $b$   |
|-------|------------|-------|-------|-------|-------|
| $\Delta b = 1, \Delta C = 0, \Delta S = -1$ | $B_s \rightarrow D_2$ | 0.017 | 0.556 | -0.008 | 0.011 |
|       | $B_s \rightarrow D_{s2}$ | 0.019 | 0.739 | -0.011 | 0.014 |
| $\Delta b = 0, \Delta C = -1, \Delta S = -1$ | $B_s \rightarrow B_2$ | 0.100 | 2.722 | -0.034 | 0.148 |
|       | $B_s \rightarrow B_{s2}$ | 0.119 | 3.632 | -0.049 | 0.165 |
| $\Delta b = 1, \Delta C = 1, \Delta S = 0$ | $B_s \rightarrow \chi_{c2}$ | 0.023 | 1.411 | -0.017 | 0.019 |
Table III. Decay amplitudes of $B_c \rightarrow PT$ decays for Cabibbo-favored modes in Charm changing and Bottom changing decays

| Decays                                      | Amplitude                                                                 |
|---------------------------------------------|---------------------------------------------------------------------------|
| $\Delta b = 0, \Delta C = -1, \Delta S = -1$ |                                                                           |
| $B_c^+ \rightarrow \pi^+ B_{s2}^0$          | $a_1 f_\pi F_{B_c \rightarrow B_{s2}} (m_{\pi}^2) V_{ct} V_{ud}^*$         |
| $B_c^+ \rightarrow K^0 B_{s2}^+$            | $a_2 f_K F_{B_c \rightarrow B_{s2}} (m_K^2) V_{ct} V_{ud}^*$               |
| $\Delta b = 1, \Delta C = 1, \Delta S = 0$ |                                                                           |
| $B_c^+ \rightarrow \pi^- \chi_{c2}$         | $a_1 f_\pi F_{B_c \rightarrow \chi_{c2}} (m_{\pi}^2) V_{cb} V_{ud}^*$     |
| $B_c^+ \rightarrow D^0 D_{s2}^-$            | $a_2 f_D F_{B_c \rightarrow D_{s2}^-} (m_D^2) V_{cb} V_{ud}^*$             |
| $\Delta b = 1, \Delta C = 0, \Delta S = -1$ |                                                                           |
| $B_c^+ \rightarrow \pi^0 D_{s2}^-$          | $\frac{1}{\sqrt{2}} a_1 f_\pi F_{B_c \rightarrow D_{s2}^-} (m_{\pi}^2) V_{ub} V_{us}^*$ |
| $B_c^+ \rightarrow \eta D_{s2}^-$           | $\frac{1}{\sqrt{2}} a_2 f_\eta \sin \phi_p F_{B_c \rightarrow D_{s2}^-} (m_{\eta}^2) V_{ub} V_{us}^*$ |
| $B_c^+ \rightarrow K^- D_{s2}^0$            | $a_1 f_K F_{B_c \rightarrow D_{s2}^-} (m_K^2) V_{ub} V_{us}^*$             |
| $B_c^+ \rightarrow \eta' D_{s2}^-$          | $\frac{1}{\sqrt{2}} a_2 f_{\eta'} \cos \phi_p F_{B_c \rightarrow D_{s2}^-} (m_{\eta'}^2) V_{ub} V_{us}^*$ |
| $B_c^+ \rightarrow D_{s}^- \chi_{c2}$       | $a_1 f_D F_{B_c \rightarrow \chi_{c2}} (m_D^2) V_{cb} V_{cs}^*$             |
| $B_c^+ \rightarrow \eta, D_{s2}^-$          | $a_2 f_\eta F_{B_c \rightarrow D_{s2}^-} (m_{\eta}^2) V_{cb} V_{cs}^*$     |
Table IV. Decay amplitudes of $B_c \rightarrow VT$ decays for Cabibbo-favored modes in Bottom changing decay

| Decays                           | Amplitude                                      |
|----------------------------------|------------------------------------------------|
| $\Delta b=1, \Delta C = 1, \Delta S = 0$ |                                               |
| $B_c^+ \rightarrow \rho^- \chi_{c2}$ | $a_1 m_\rho f_\rho F^{B_c^+ \rightarrow \chi_{c2}}_{\rho \rho} V^*_{cb V_{ud}}$ |
| $B_c^+ \rightarrow D^{*0}_{s2}$      | $a_2 m_{D_s} f_{D_s} F^{B_c^+ \rightarrow D^{*0}_{s2}}_{D_s \rho} V^*_{cb V_{ud}}$ |
| $\Delta b=1, \Delta C = 0, \Delta S = -1$ |                                         |
| $B_c^+ \rightarrow \rho^0 D_{s2}^-$  | $1 \sqrt{2} a_2 m_\rho f_\rho F^{B_c^+ \rightarrow D_{s2}^0} V^*_{ab V_{us}}$ |
| $B_c^+ \rightarrow \omega D_{s2}^-$  | $1 \sqrt{2} a_2 m_{\omega} f_{\omega} \sin \phi \ F^{B_c^+ \rightarrow D_{s2}^0} V^*_{ab V_{us}}$ |
| $B_c^+ \rightarrow K^{*-} \bar{D}_2^0$ | $a_1 m_K f_K F^{B_c^+ \rightarrow K^{*-} \bar{D}_2^0} V^*_{ab V_{us}}$ |
| $B_c^+ \rightarrow \phi D_{s2}^-$    | $1 \sqrt{2} a_2 m_\phi f_\phi \cos \phi \ F^{B_c^+ \rightarrow D_{s2}^0} V^*_{ab V_{us}}$ |
| $B_c^+ \rightarrow D_s^{*-} \chi_{c2}$ | $a_1 m_{D_s^*} f_{D_s^*} F^{B_c^+ \rightarrow D_s^{*-} \chi_{c2}} V^*_{cb V_{cs}}$ |
| $B_c^+ \rightarrow J / \psi D_{s2}^*$ | $a_2 m_{J / \psi} f_{J / \psi} F^{B_c^+ \rightarrow D_{s2}^*} V^*_{cb V_{cs}}$ |
Table VI. Branching ratios of $B_c \to PT$ decays for Cabibbo-favored modes in Charm changing and Bottom changing decays

| Decays                          | Branching ratios          | This work | [13] | [14] |
|--------------------------------|---------------------------|-----------|------|------|
| $\Delta b = 0, \Delta C = -1, \Delta S = -1$ |                            |           |      |      |
| $B_c^+ \to \pi^+ B_{s2}^0$       | $3.0 \times 10^{-4}$       |           |      |      |
|                                  |                            | -         |      |      |
| $B_c^+ \to \bar{K}^0 B_2^+$     | $1.0 \times 10^{-3}$       |           |      |      |
|                                  |                            | -         |      |      |
| $\Delta b = 1, \Delta C = 1, \Delta S = 0$ |                            |           |      |      |
| $B_c^- \to \pi^- \chi_{c2}$     | $2.0 \times 10^{-4}$       |           |      |      |
|                                  |                            | $2.48 \times 10^{-4}$ |      |      |
|                                  |                            | $7.5 \times 10^{-5}$ |      |      |
| $B_c^- \to D^0 D_2^-$           | $4.0 \times 10^{-6}$       |           |      |      |
|                                  |                            | -         |      |      |
| $\Delta b = 1, \Delta C = 0, \Delta S = -1$ |                            |           |      |      |
| $B_c^- \to \pi^0 D_{s2}^-$      | $6.8 \times 10^{-10}$      |           |      |      |
|                                  |                            | -         |      |      |
| $B_c^- \to \eta D_{s2}^-$       | $3.6 \times 10^{-10}$      |           |      |      |
|                                  |                            | -         |      |      |
| $B_c^- \to K^- D_2^0$           | $1.6 \times 10^{-8}$       |           |      |      |
|                                  |                            |           |      |      |
| $B_c^- \to \eta' D_{s2}^-$      | $3.1 \times 10^{-10}$      |           |      |      |
|                                  |                            | -         |      |      |
| $B_c^- \to D^- \chi_{c2}$       | $3.2 \times 10^{-4}$       |           |      |      |
|                                  |                            | $4.54 \times 10^{-4}$ |      |      |
|                                  |                            | $1.54 \times 10^{-4}$ |      |      |
| $B_c^- \to \eta_c D_s^-$        | $1.4 \times 10^{-5}$       |           |      |      |
|                                  |                            | -         |      |      |
Table VII. Branching ratios of $B_c \rightarrow VT$ decays for Cabibbo-favored modes in Bottom changing decays

| Decays                          | Branching ratios       | This work | [13]   | [14]   |
|--------------------------------|------------------------|-----------|--------|--------|
| $\Delta b = 1, \Delta C = 1, \Delta S = 0$ |                         |           |        |        |
| $B_c^- \rightarrow \rho^- \chi_{c2}$ | 2.4×10^-4             | 5.18×10^-4 | 2.38×10^-4 |
| $B_c^- \rightarrow D^{*0} D_s^-$     | 8.9×10^-6             | -         | 3.42×10^-7 |
| $\Delta b = 1, \Delta C = 0, \Delta S = -1$ |                         |           |        |        |
| $B_c^- \rightarrow \rho^0 D_{s2}^-$  | 8.4×10^-10            | -         | 7.91×10^-11 |
| $B_c^- \rightarrow \omega D_{s2}^-$  | 5.3×10^-11            | -         | 3.94×10^-11 |
| $B_c^- \rightarrow K^- D_{s2}^0$     | 1.6×10^-8             | -         | 4.52×10^-10 |
| $B_c^- \rightarrow \phi D_{s2}^-$    | 1.2×10^-9             | -         | 4.81×10^-11 |
| $B_c^- \rightarrow D_s^- \chi_{c2}$  | 8.8×10^-4             | 2.4×10^-3 | 5.25×10^-4 |
| $B_c^- \rightarrow J / \psi D_{s2}^-$| 9.6×10^-3             | -         | 2.06×10^-3 |