Exclusive semileptonic decays of open bottom mesons into pseudoscalar open charm mesons

Arpit Parmar[1],* Bhavin Patel[2],† and P C Vinodkumar[1‡]
[1]Department of Physics, Sardar Patel University, Vallabh Vidyanagar-388120. and
[2]P D Patel Institute of Applied Sciences, CHARUSAT, CHANGA-388421.

Introduction

The study of semileptonic decays of heavy quarks provides the cleanest avenue for the determination of the Cabibbo-Kobayashi-Maskawa matrix elements, which are fundamental parameters in the standard model of particle physics. The coupling strength of the weak $b \to c$ transition is proportional to $|V_{cb}|$, which has been measured in exclusive semileptonic transitions $B \to D\ell\bar{\nu}_\ell$ [1, 2].

Theory

The semileptonic B_q meson decay amplitude is determined by the matrix elements of the weak Hamiltonian as [3],

$$H_W = \frac{G_F}{\sqrt{2}} V_{cb}[\bar{c}\gamma_\mu(1-\gamma_5)b][\bar{e}\gamma^\mu(1-\gamma_5)\nu_e] \tag{1}$$

The vector and axial vector part of weak hamiltonian can be parametrized into model dependent form factors as,

$$\begin{aligned}\langle D_q(p^{'})|V^\mu|B_q(p)\rangle &= f_+(q^2)(p+p^{'})_\mu \\ &+ f_-(q^2)(p-p^{'})_\mu\end{aligned} \tag{2}$$

On the basis of HQET, the most general form of the transition discussed by Eqns. 2 can be expressed as [3],

$$\frac{1}{\sqrt{M_{B_q}M_{D_q}}}\langle D_q(v^{'})|V^\mu|B_q(v)\rangle = (v+v^{'})^\mu \xi(\omega) \tag{3}$$

Where $\xi(\omega)$ is a universal function known as Isgur Wise function and ω is given by,

$$w = v \cdot v^{'} = \frac{\left[m^2_{B_q} + m^2_{D_q} - q^2\right]}{2m_{B_q}m_{D_q}} \tag{4}$$

The Isgur Wise function, $\xi(\omega)$ can be evaluated according to the relation given by [4],

$$\xi(\omega) = \frac{2}{\omega-1}\left\langle j_0\left(2E_q\sqrt{\frac{\omega-1}{\omega+1}}r\right)\right\rangle \tag{5}$$

Where E_q is the binding energy of the decaying meson, which can be evaluated by solving the Schrodinger equation $H\psi = E\psi$ and the quantity within the angular bracket, $\langle A\rangle$ corresponds to

$$\langle A\rangle = \int_0^\infty dr r^2 R_i(r)A(r)R_f(r) \tag{6}$$

Consequently, the form factors $f_\pm(q^2)$ correspond to the D_q final state are related to the Isgur Wise function as [3]

$$f_\pm(q^2) = \xi(\omega)\frac{m_{B_q} \pm m_{D_q}}{2\sqrt{m_{B_q}m_{D_q}}} \tag{7}$$

The differential decay rates $d\Gamma/dq^2$ for $B_q \to D_q(\ell^+\nu_\ell)$ then be expressed in terms of $f_\pm(q^2)$ as [3],

$$\begin{aligned}\frac{d\Gamma}{dq^2}(B_q \to \quad D_q e^-\nu_e) &= \frac{G_F^2|V_{cb}|^2|f_+|^2}{192\pi^3 m^3_{B_q}} \\ &\times \left[(q^2 - m^2_{B_q} - m^2_{D_q})^2 - 4m^2_{B_q}m^2_{D_q}\right]^{3/2}\end{aligned} \tag{8}$$

Extraction of masses and radial wave function

For the description of mass spectra and form of wave function of charmonium state we

*Electronic address: arpitspu@yahoo.co.in
†Electronic address: azadpatel2003@yahoo.co.in
‡Electronic address: pothodivinod@yahoo.com

TABLE I: Branching ratio (in %) for exclusive semileptonic decays of open bottom mesons into open charm mesons

ν	$B \to D\ell\bar{\nu}_\ell$	$B_s \to D_s\ell\bar{\nu}_\ell$
0.1	0.80	1.41
0.3	1.42	2.36
0.5	1.94	2.97
0.7	2.32	3.41
0.8	2.47	3.59
0.9	2.63	3.69
1.0	2.77	3.83
1.1	2.86	3.94
1.3	3.08	4.12
1.5	3.22	4.24
1.7	3.37	4.36
1.9	3.47	4.47
2.0	3.53	4.51
[5]	2.39 ± 0.12	7.9 ± 2.4
[6]	2.34 ± 0.03	

adopt here the potential model with the potential as $V(r) = -\alpha_s/r + Ar^\nu$. Here A and ν are the potential strength and potential exponent respectively. For the present study we vary range of potential exponent as $0.1 \leq \nu \leq 2.0$. For different choices of potential exponent ν radial wave functions are obtained by solving the nonrelativistic schrodinger equation numerically.

Results and Discussion

The compared semileptonic branching ratios of B_q into D_q mesons are shown in Table I against different potential exponent ν. Other theoretical and experimental results are also shown for comparison. Our results show agreement with the experimental observations for choices of potential exponent, ν in the range $0.7 \leq \nu \leq 0.8$ for $B \to D\ell^+\ell^-$. This shows weaker interquark potential in this type of decays. However, in the case of $B_s \to D_s\ell^+\ell^-$ our results do not compare with the experimental value. However large uncertainty in the experimental observation warranted more precise measurements before further conclusions.

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