Weak B Decays into Orbitally Excited Charmed Mesons

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The BaBar Collaboration has recently reported branching fractions for semileptonic decays of the B meson into final states with charged and neutral $D_1(2420)$ and $D_2^*(2460)$, two narrow orbitally excited charmed mesons. We evaluate these branching fractions within the framework of a constituent quark model in two steps, one which involves a semileptonic decay and the other one mediated by a strong process. Our results are in agreement with the experimental data.

1 Introduction

Different collaborations have recently reported semileptonic B decays into orbitally excited charmed mesons providing detailed results of branching fractions [1,2]. These data offer new theoretical possibilities to test meson models as far as they include a weak decay followed by a strong one.

All these magnitudes can be consistently calculated in the framework of constituent quark models because they can simultaneously account for the hadronic part of the weak process and the strong meson decays. In this context meson strong decay has been described successfully in phenomenological models, like the $^3P_0$ model [3] or in microscopic models (see Refs. [4,5]). The matrix element for the weak process factorizes into a leptonic and a hadronic part. It is the hadronic part that contains the non-perturbative strong interaction effects and we shall evaluate it within the constituent quark model (CQM) of Ref. [6] which successfully describes hadron phenomenology and reactions. Details of the calculation can be found in Ref. [7].

2 Theoretical framework

2.1 Constituent quark model

Spontaneous chiral symmetry breaking of the QCD Lagrangian together with the perturbative one-gluon exchange (OGE) and the non-perturbative confining interaction are the

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main pieces of potential models. Using this idea, Vijande *et al.* [6] developed a model of the quark-quark interaction which is able to describe meson phenomenology from the light to the heavy quark sector. Further details can be found in Ref. [6].

In order to find the quark-antiquark bound states, we solve the Schrödinger equation by Rayleigh-Ritz variational principle. We use the Gaussian Expansion Method [8] that provides enough accuracy and makes the subsequent evaluation of the decay amplitude matrix elements easier.

Model parameters are given in Ref [9].

2.2 Weak and strong decays

In the weak decay we have a $\bar{b} \to \bar{c}$ transition at the quark level and we need to evaluate the hadronic matrix elements of the weak current

$$J^{bc}_{\mu}(0) = \overline{\psi}_b(0)\gamma_\mu(I - \gamma_5)\psi_c(0). \tag{1}$$

The hadronic matrix elements involved in these processes can be parametrized in terms of form factors. The expression of the hadron tensor in the helicity formalism [10] has been calculated following Ref. [11].

To describe the meson decay process $A \to B + C$, the ${}^3P_0$ decay model assumes that a quark and an antiquark are created with vacuum quantum numbers. The created $q\bar{q}$ pair together with the $q\bar{q}$ pair from the initial meson regroups in the two outgoing mesons via a quark rearrangement process. For the ${}^3P_0$ decay model, the interaction Hamiltonian is given by

$$H_I = g \int d^3x \overline{\psi}(\vec{x})\psi(\vec{x}) \tag{2}$$

where g is related to the dimensionless constant giving the strength of the $q\bar{q}$ pair creation from the vacuum as $\gamma = \frac{g}{2m_q}$.

In the microscopic decay models, the strong decays are driven by the interquark Hamiltonian which determines the spectrum. In our case we have the one-gluon exchange and a mixture of scalar and vector Lorentz confining interactions appearing as the kernels. These interactions and their associated decay amplitudes are undoubtedly all present and should be added coherently. The Hamiltonian of the interaction can be written as

$$H_I = \frac{1}{2}\int d^3x d^3y\, J^a(\vec{x})K(|\vec{x}-\vec{y}|)J^a(\vec{y}), \tag{3}$$

where current $J^a(\vec{x})$ in Eq. (3) is assumed to be a color octet. Calculation details referred to the microscopic model can be found in Ref. [12].

	Belle [1] $(\times 10^{-3})$	BaBar [2] $(\times 10^{-3})$	$^3P_0$ $(\times 10^{-3})$	Mic. $(\times 10^{-3})$
$D_1(2420)$				
$\mathcal{B}(B^+ \to \overline{D}_1^0 l^+ \nu_l)\mathcal{B}(\overline{D}_1^0 \to D^{*-}\pi^+)$	$4.2 \pm 0.7 \pm 0.7$	$2.97 \pm 0.17 \pm 0.17$	2.57	2.57
$\mathcal{B}(B^0 \to D_1^- l^+ \nu_l)\mathcal{B}(D_1^- \to \overline{D}^{*0}\pi^-)$	$5.4 \pm 1.9 \pm 0.9$	$2.78 \pm 0.24 \pm 0.25$	2.39	2.39
$D_2^*(2460)$				
$\mathcal{B}(B^+ \to \overline{D}_2^{*0} l^+ \nu_l)\mathcal{B}(\overline{D}_2^{*0} \to D^-\pi^+)$	$2.2 \pm 0.3 \pm 0.4$	$1.4 \pm 0.2 \pm 0.2^{(*)}$	1.43	1.47
$\mathcal{B}(B^+ \to \overline{D}_2^{*0} l^+ \nu_l)\mathcal{B}(\overline{D}_2^{*0} \to D^{*-}\pi^+)$	$1.8 \pm 0.6 \pm 0.3$	$0.9 \pm 0.2 \pm 0.2^{(*)}$	0.79	0.75
$\mathcal{B}(B^+ \to \overline{D}_2^{*0} l^+ \nu_l)\mathcal{B}(\overline{D}_2^{*0} \to D^{(*)-}\pi^+)$	$4.0 \pm 0.7 \pm 0.5$	$2.3 \pm 0.2 \pm 0.2$	2.22	2.22
$\mathcal{B}(B^0 \to D_2^{*-} l^+ \nu_l)\mathcal{B}(D_2^{*-} \to \overline{D}^0\pi^-)$	$2.2 \pm 0.4 \pm 0.4$	$1.1 \pm 0.2 \pm 0.1^{(*)}$	1.34	1.38
$\mathcal{B}(B^0 \to D_2^{*-} l^+ \nu_l)\mathcal{B}(D_2^{*-} \to \overline{D}^{*0}\pi^-)$	< 3	$0.7 \pm 0.2 \pm 0.1^{(*)}$	0.74	0.70
$\mathcal{B}(B^0 \to D_2^{*-} l^+ \nu_l)\mathcal{B}(D_2^{*-} \to \overline{D}^{(*)0}\pi^-)$	< 5.2	$1.8 \pm 0.3 \pm 0.1$	2.08	2.08
$\mathcal{B}_{D/D^{(*)}}$	0.55 ± 0.03	$0.62 \pm 0.03 \pm 0.02$	0.65	0.66

Table 1: Most recent experimental measurements reported by Belle and BaBar Collaborations and their comparison with our results. The symbol $(*)$ indicates the estimated results from the original data using $B_{D/D^{(*)}}$.

3 Results

The final results and their comparison with the experimental data are given in Table 1. Both $^3P_0$ and microscopic models predict similar branching ratios. The predictions for the $B \to D_1 l \nu_l$ and $B \to D_2^* l \nu_l$ are in good agreement with the latest experimental measurements by the BaBar Collaboration. They are significantly smaller than the Belle data, though.

4 Conclusions

We have performed a calculation of the branching fractions for the semileptonic decays of B meson into final states containing the narrow orbitally excited charmed mesons.

We worked in the framework of the constituent quark model of Ref. [6]. We have calculated the semileptonic decay rates within the helicity formalism of Ref. [10] and following the work in Ref. [11]. The strong decay widths have been calculated using two models, the $^3P_0$ model and a microscopic model based on the quark-antiquark interactions present in the CQM model of Ref. [6].

From the experimental point of view, Belle and BaBar Collaborations provide their most recent measurements for the B meson in Refs. [1] and [2], respectively.

Our results for B semileptonic decays into $D_1(2420)$ and $D_2(2460)$ are in good agreement with the latest experimental measurements by the BaBar Collaboration.

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