0^+ and 1^+ States of B and B_s Mesons

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(Dated: 2004/10/11)

Predicted masss of $J^P = 0^+$ and 1^+ states of D_{sJ} and D by a potential model proposed some time ago have recently been confirmed by BaBar and Bell experiments within one percent accuracy. In the model both the Hamiltonian and wave functions are expanded in $1/m_Q$ with m_Q heavey quark mass, i.e., it is the potential model respecting heavy quark symmetry.

In this Letter, decay modes of 0^+ and 1^+ states of B and B_s mesons are discussed using the predicted masses of this model.

PACS numbers:

I. INTRODUCTION

The BaBar [1]'s discovery of $D_{sJ}(2317)$ and $D_{sJ}(2457)$ of the system c and s quarks has inspired theorists [2, 3] to explain these states in some way because a well-known potential model [4, 5] failed to expound masses of these states. This discovery has been soon confirmed by by CLEO and Belle [6]. These D_{sJ} states are narrow because isospin violation and K meson mass threshold prohibit them to decay into lower states $D_s(1968)$ and $D_s^*(2112)$. This is another reason why theorists are interested in these states and are trying to explain their branching ratios, too.

Soon after the discovery another set of heavy mesons, $D_0^{*0}(2308)$ and $D_1^{'0}(2427)$ of c and u/d quarks which have the same quantum numbers $j^P = 0^+$ and 1^+ as D_{sJ}, has been discovered by Belle [7]. Again masses of these states cannnot be fitted with thoes of a potential model [4, 5]. These states D_0^{*0} and $D_1^{'0}$ have not restriction like D_{sJ}, hence their decay (like $D\pi$ and $D^*\pi$) width become broad.

To explain masses of D_{sJ}, Bardeen, Eichten, Hill and others [2, 3] proposed an interesting idea of an effective Lagrangian with chiral symmetries of light quarks and heavy quark symmetry. The heavy meson states with the total angular momentum $j = 0$ and $j = 1$ combined with $s_\ell = 1/2$, which is the total angular momentum of the light quark degrees of freedom, make the parity doublets $(0^-, 0^+)$ and $(1^-, 1^+)$, respectively, and the members in each doublet degenerate in a limit of chiral symmetry. Furthermore, the two states $(0^-, 1^-)$ degenerate in a limit of heavy quark symmetry, as well as $(0^+, 1^+)$ do. These doublets are called the heavy spin multiplets. Their model cannot calculate masses themselves but mass differences by using the modified Goldberger-Treiman relation. This is why some people have proposed a modifed potential model by using a DK bound state.[8]

In the papers [4, 5], they proposed a relativised potential model in which they included $\sqrt{p^2 + m_q^2}$ as a kinetic term and spin- dependent interaction terms where linear-rising confining as well as short-range Coulomb potentials are taken into account. This model, however, could not reproduce the masses of $D_{sJ}(2317)$ and $D_{sJ}(2457)$. Thus, there appear some discussions [8] that a potential model is not appropriate to describe these states. Evne though they have taken an infinite heavy quark mass limit in the second paper [5], they could not reproduce $D_{sJ}(1^+)$ mass.

The above potential model does not completely and consistently respect heavy quark symmetry and does not treat quarks as Dirac particles. Some time ago, two of the authors (T.M. and T.M.) [9] have proposed a new bound

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TABLE I: Comparison of higher D and D_s meson masses (units in MeV)

J^P	$D(0^+)$	$D(1^+)$	$D_s(0^+)$	$D_s(1^+)$
observed	2308	2427	2317	2457
predicted	2304	2449	2339	2487

TABLE II: Higher B and B_s meson masses taken from [9] (units in MeV)

J^P	$B(0^+)$	$B(1^+)$	$B_s(1^-)$	$B_s(0^+)$	$B_s(1^+)$
predicted	5697	5740	5440	5716	5760

state equation for atomlike mesons, i.e., heavy mesons composed of a heavy quark and a light antiquark, in which they expand the lowest bound state equation in $1/m_Q$ with m_Q heavy quark mass. In this model compared with [4, 5], quarks are treated as four-spinor particles from the beginning and both the Hamiltonian and wave functions are expanded in $1/m_Q$ so that our model treats quarks as relativistic as possible and consistently takes into account heavy quark symmetry within a potential model. Our prediced masses for these states, D_{sJ} and D_0^{*0} and $D_1^{'0}$, are in good agreement within one percent accuracy when calculated at the first order in $1/m_Q$. See Table I and II below and Tables III and IV in [9].

In this Letter, having confirmed that our model have well succeeded in predicting masses of recent discovered heavy mesons, we predict masses of 0^-, 0^+, and 1^+ of B and 0^+ and 1^+ of B_s mesons by citing the evaluated values in [9]. We also discuss their decay modes whether these mesons violate isospin symmetry or not and whether mass difference between 0^+ (1^+) and 0^- (1^-) is less than the BK/B^*K-mass threshold or not. We expect these higher states of B and B_s mesons can be detected in CDF/LHC experiments.

II. HIGHER B AND B_s MESON MASSES AND THEIR DECAY MODES

Our prediction in [9] of B and B_s meson masses in the first order of $1/m_Q$ corrections is given by Table II. Considering the fact that our predictions of D/D_s masses are well reprodeuced by our model within one percent accuracy as seen in Table I, we expect masses of these B and B_s mesons are similarly within one percent accuracy to be observed.

Let us discuss decay modes of 0^+ and 1^+ states of B and B_s mesons taking into account these meson maases given by Table II.[9]

(1) $B_s(1^-) \to B_s(0^-) + \gamma$

(2) $B(0^+) \to B(0^-) + \pi$ with broad decay width

(3) $B_s(0^+) \to B_s(0^-) + \pi$ with narrow decay width

(4) $B_s(1^+) \to B_s(1^-) + \pi$ with narrow decay width

Comments are given as follows.

1. Decay $B_s(1^-) \to B_s(0^-) + \gamma$ is similar to $B(1^-) \to B(0^-) + \gamma$ i.e., $B^* \to B + \gamma$, and is dominat decay mode.
2. Decay width of $B(0^+) \to B(0^-) + \pi$ is broad because this is strong decay and this is not prohibited by isospin invariance since $I(B(0^-)) = I(B(0^+)) = 1/2$ while $I(\pi) = 1$.
3. Decay width of $B_s(0^+) \to B_s(0^-) + \pi$ is expected very narrow, a few MeV like the decay of $D_s(0^+) \to D_s(0^-) + \pi$ since this decay mode is prohibited by isospin invariance due to $I(B_s(0^+)) = I(B_s(0^-)) = 0$ while $I(\pi) = 1$ and the masses are below BK threshold.
4. Decay width of $B_s(1^+) \to B_s(1^-) + \pi$ is also expected very narrow, a few MeV like the decay of $D_s(0^+) \to D_s(0^-) + \pi$ since this decay mode is prohibited by isospin invariance due to $I(B_s(1^+)) = I(B_s(1^-)) = 0$ while $I(\pi) = 1$ and the masses are below B^*K threshold.

Here $B_s(0^-) = B_s(5370)$, $D_s(0^-) = D_s^{\pm}(1969)$, $D_s(1^-) = D_s^{*\pm}(2112)$, $D_s(0^+) = D_{sJ}(2317)$, and $D_s(1^+) = D_{sJ}(2457)$.V.[10] We expect these higher states of B and B_s mesons can be detected in CDF experiments.

III. CHIRAL LIMIT OF H_0

Let us see how to realize chiral symmetry in our model to understand the paper by Bardeen and Hill[3]. The lowest order Hamiltonian in our model is given by[9]

$$H_0 = \vec{\alpha}_q \cdot \vec{p} + \beta_q \left(m_q + S(r)\right) + V(r). \tag{1}$$

which has a chiral limit when one set $m_q = S(r) = 0$ and the corresponding Hamiltonian is given by

$$H_0^{chiral} = \vec{\alpha}_q \cdot \vec{p} + V(r). \tag{2}$$

From our point of view, mass splitting occurs as follows.

(1) Start from the chiral limit Hamiltonian, Eq.(2), together with no $1/m_Q$ corrections with m_Q heavy quark mass. In this stage all the masses are degenerate (m_Q=$m(0^-) = m(1^-) = m(0^+) = m(1^+)$).

(2) Mass terms (m_q and a scalar potential $S(r)$), i.e., explicit chiral breaking terms are inserted, Eq.(1), and degeneracy is partially broken ($m(0^-) = m(1^-)$ and $m(0^+) = m(1^+)$) since there still remains degeneracy due to the quantum number k.[12]

(3) Finally by including $1/m_Q$ terms all the degeneracy is resolved and the mass values in Table I and II are given.

Notice that the quantum number k plays an important role in our model to see how the states are classified and how the degeneracy is resolved. The above procedure may be depicted in Figure III.

FIG. 1: Procedure how the degeneracy is resolved in our potential model
Figure 1

On the other hand, the procedure taken by Bardeen and Hill[3] can be stated as follows.

(1) Start from the chiral as well as infinite heavy quark mass limit as like our model.

(2) Include a finite heavy quark mass to partially resolve degeneracy. ($m(0^-) = m(0^+)$ and $m(1^-) = m(1^+)$ which are called parity doublets.)

(3) Finally by including a finite light quark mass effects, the modified Goldber-Treiman relation, all the degeneracy is resolved.

Comparing these two procedures, one can easily see that our model naturally explains how to resolve degeneracy among 0^- and 1^- and/or 0^+ and 1^+ due to the quantum number k and clarify the origin of mass splitting. Namely the interpretation by Bardeen and Hill is not the unique way to explain the mass splitting. There still remains a way to explain it using a potential model. Moreover it is hopeful to give the absolute values of mass as seen in Tables I and II.

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[1] BaBar Collaboration, B. Aubert *et al.*, Phys. Rev. Lett. **90**, 242001 (2003).
[2] W. A. Bardeen, E. J. Eichten, and C. T. Hill, Phys. Rev. D **68**, 054024 (2003).
[3] W. A. Bardeen and C. T. Hill, Phys. Rev. D **49**, 409 (1994); M. A. Nowak, M. Rho, and I. Zahed, *ibid.* **48**, 4370 (1993); A. Deandrea, N. Di Barolomeo, R. Gatto, G. Nrdulli, and A. D. Plosa, *ibid.* **58**, 034004 (1998); A. Hiorth and J. O. Eeg, *ibid.* **66**, 074001 (2002).
[4] S. Godfrey and N. Isgur, Phys. Rev. D **32**, 189 (1985).
[5] S. Godfrey and R. Kokoski, Phys. Rev. D **43**, 1679 (1991).
[6] CLEO Collaboration, D. Besson *et al.*, Phys. Rev. D **68**, 032002 (2003); Belle Collaboration, Y. Mikami *et al.*, Phys. Rev. Lett. **92**, 012002 (2004).
[7] Belle Collaboration, K. Abe *et al.*, Phys. Rev. D **69**, 1120022 (2004); Talk given by K. Abe at the *International Workshop PENTAQUARK04* held at Spring-8 in July 19-23, 2004.
[8] T. Barnes, F. E. Close, and H. J. Lipkin, Phys. Rev. D **68**, 054006 (2003).
[9] T. Matsuki and T. Morii, Phys. Rev. D **56**, 5646 (1997).
[10] Reiview of Partile Physics edited by K. Hagiwara et al., Phys. Rev. D **66**, 010001 (2002).
[11] J. Morishita, M. Kawaguchi, and T. Morii, Phys. Rev. D **37**, 159 (1988).
[12] T. Matsuki, K. Mawatari, T. Morii, and K. Sudoh, hep-ph/0408326.