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0^+ and 1^+ states of B and B_s mesons

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Abstract

Predicted masses of $J^P = 0^+$ and 1^+ states of D_{sJ} and D by a potential model proposed some time ago by two of us (T.M. and T.M.), in which the Hamiltonian and wave functions are expanded in $1/m_Q$ with m_Q heavy quark mass respecting heavy quark symmetry, have recently been confirmed by BaBar and Belle experiments within one percent accuracy.

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.

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1. Introduction

The BaBar's discovery [1] of $D_{sJ}(2317)$ and $D_{sJ}(2460)$ 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 CLEO and Belle [6]. These D_{sJ} states are narrow because isospin violation and DK/D^*K 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 cannot be fitted with those of a potential model [4,5]. These states D_0^{*0} and $D_1'^0$ have no restriction like D_{sJ} and hence their decay (like $D\pi$ and $D^*\pi$) width becomes broad.

To explain masses of D_{sJ}, Bardeen, Eichten, Hill, and others [2,3] proposed an interesting idea of an

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effective Lagrangian with chiral symmetries of light quarks and heavy quark symmetry. The heavy meson states with the total angular momentum $J = 0$ and $J = 1$ with $j_q = 1/2$, 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, $(0^-, 1^-)$ and $(0^+, 1^+)$, are called the heavy spin multiplets. Though their model can reproduce well the mass difference between members in each parity doublet by using the modified Goldberger–Treiman relation, unfortunately it cannot calculate masses themselves. This is why some people have proposed a modified potential model by using a DK bound state [8].

Several years ago, Godfrey, Isgur, and Kokoski proposed a relativized potential model [4,5], in which they included $\sqrt{p^2 + m^2}$ 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 $D_{sJ}(2460)$. Even though they have taken an infinite heavy quark mass limit in the second paper [5], they could not reproduce $D_{sJ}(1^+)$ mass and their calculated masses exceeded DK/D^*K threshold. Thus, there appear some discussions [8] that a potential model is not appropriate to describe these states.

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] proposed a new bound state equation for atomlike mesons, i.e., heavy mesons composed of a heavy quark and a light antiquark. 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 predicted 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 1 in this Letter and Tables III and IV in [9].

Table 1
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

We have used a current quark mass for u and d quarks ($= 10$ MeV) instead of a constituent quark mass when calculating heavy mesons in [9]. We would like to comment on that reason. The quark model has been successful to describe meson/baryon states using constituent quark masses in the low energy region or for quarkonium states, where the nonrelativistic treatment works well. However, we believe that the heavy mesons we are treating is not in that kind. We are considering the situation that the mass is running, i.e., quantum effects are important to describe the heavy mesons though the running coupling is not taken into account in our paper [9]. When the running mass is adopted, u and d quark masses should be around 10 MeV for the B meson energy ($\simeq 5$ GeV). We have actually searched for the numerical solution for heavy mesons with the constituent quark masses in [9] but in vain. As for the discussion of light quark masses in heavy mesons $Q\bar{q}$ which are treated with a relativistic equation, see also [10].

In this Letter, having confirmed that our model has well succeeded in predicting masses of recently discovered heavy mesons, we predict masses of 0^+ and 1^+ of B and 0^+, 1^- and 1^+ of B_s mesons by citing the evaluated values in [9]. Here 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 Tevatron/LHC experiments.

2. 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 in Table 2. Considering the fact that D/D_s masses have been well predicted by our model within one percent accuracy as seen in Table 1, we expect masses of these B and