A Comprehensive Interpretation of the D_{sJ} states

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We propose that the $D_{sJ}(2860)$ and $D_{sJ}(3040)$ are $D_1(2420)K$ and $D^*(2600)K$ bound states, respectively. Together with the famous $D^*_{s0}(2317)$ and $D_{s1}(2460)$, they belong to a family of kaonic bound states. With input only from the mass of the $D^*_{s0}(2317)$, both the predicted mass and decay pattern of the $D_{sJ}(2860)$ agree remarkably well with the measurements. The properties of the $D_{sJ}(3040)$ agree with the data as well. More kaonic bound states are also predicted awaiting experimental test. We suggest to search for a predicted $D^*_{s2}(2910)$ with a 10 MeV width in the D^*K channel and the $D_{sJ}(3040)$ in the $D_s\omega$ channel.

The constituent quark model has achieved a great success in the hadron spectroscopy until recent years when many new hadronic states were observed. The $D^*_{s0}(2317)$ and $D_{s1}(2460)$ are two outstanding examples. After their discovery, more charm-strange mesons were found, including the $D^*_{s1}(2700)$ [1, 2], $D_{sJ}(2860)$ [1] and $D_{sJ}(3040)$ [3]. The mass, decay patterns and angular distribution of the $D^*_{s1}(2700)$ were measured to be consistent with the expectation of a $2S$ $J^P = 1^-$ state. The information on the $D_{sJ}(3040)$ is not enough for identifying its nature. Among the three states, the $D_{sJ}(2860)$ is the most puzzling one.

The ratio of the different decay modes of the $D_{sJ}(2860)$ was measured to be [4]

$$R_{D_{sJ}(2860)} = \frac{\Gamma(D_{sJ}(2860) \to D^*K)}{\Gamma(D_{sJ}(2860) \to DK)} = 1.10 \pm 0.24. \tag{1}$$

Using heavy hadron chiral perturbation theory, one can calculate such a ratio without any parameter at leading order because the D^* and D are related to each other by heavy quark spin symmetry. The ratio was calculated for various possible quantum number assignments assuming a $c\bar{s}$ nature [5]. The result for $(2S, 1^-)$ is 1.23 and agrees with the data rather well. The other possibility is $(2P, 2^+)$, and the result 0.63 is not far from the data. However, the $(2S, 1^-)$ $c\bar{s}$ meson has already been identified as the $D^*_{s1}(2700)$, and the $(2P, 2^+)$ one would have a mass as large as 3.1 GeV [6]. Hence it is a challenge to understand the properties of the $D_{sJ}(2860)$ theoretically although some models exist (for references, see [7]). As will be shown in the following, both the mass and decay patterns can be nicely described were it a $D_1(2420)K$ bound state (for more details, see [7]).

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	$D_1(2420)K$	$D_2(2460)K$	$D(2550)K$	$D^*(2600)K$	$\overline{B}_1(5720)K$	$\overline{B}_2(5747)K$
J^P	1^-	2^-	0^+	1^+	1^-	2^-
Results	2870 ± 9	2910 ± 9	2984 ± 10	3052 ± 11	6151 ± 33	6169 ± 33
Data	$2862 \pm 2^{+5}_{-2}$			$3044 \pm 8^{+30}_{-5}$		

Table 1: Predicted masses of heavy meson kaonic bound states. The experimental values are listed in the fourth row for comparison. All masses are given in MeV.

Among the models for the positive-parity charm-strange mesons $D^*_{s0}(2317)$ and $D_{s1}(2460)$, the hadronic molecular scenario (DK for $D^*_{s0}(2317)$ and D^*K for $D_{s1}(2460)$) [8–12] is very interesting because the experimental fact $M_{D_{s1}(2460)} - M_{D^*_{s0}(2317)} \simeq M_{D^*} - M_D$ emerges as its natural consequence [13]. One may ask whether there are other kaonic bound states of heavy mesons.

At low energies, the leading order interaction between the pseudo Goldstone bosons (including pions, kaons and eta for the SU(3) case) and matter fields is governed by chiral symmetry. Neglecting the Born term which is rather small, the scattering amplitude $V(s,t,u)$ is given by the so-called Weinberg-Tomozawa term. In order to obtain a bound state or a resonance, one has to perform a resummation. This can be done by using [14]

$$T(s) = V(s)[1 - G(s)V(s)]^{-1}, \tag{2}$$

where $V(s)$ is the S-wave projection of $V(s,t,u)$ and $G(s)$ consists of loop functions. In this way, the $D^*_{s0}(2317)$ and $D_{s1}(2460)$ are generated as the DK and D^*K bound states, respectively. By doing this, we have used the fact that the life time of the ground-state D and D^* is so long that their decays can be neglected in the calculations. But what is the meaning of a long life time? It should be contrasted to the range of forces which may be estimated as $1/m_\rho$ with m_ρ being the ρ-meson mass. Hence, it is natural to extend the above considerations to other heavy mesons whose width is much smaller than m_ρ (or more conservatively $2m_\pi$). There is one parameter is Eq. (2), the so-called subtraction constant $a(\mu)$ with μ being the dimensional regularization scale, which is introduced to regularize the divergent loop function. We fix the value of $a(\mu)$ to reproduce the mass of the $D^*_{s0}(2317)$ for each choice of μ. The scale μ is allowed to vary between 1 GeV and the mass of the scattered heavy meson, and in this way we estimate the uncertainties of the calculations. A family of heavy-flavor kaonic bound states can be produced. The $D^{(*)}K$ and $\overline{B}^{(*)}K$ bound states have been studied in the literature. In Table 1, results for some other states are shown in comparison with existent data. The agreement suggests that the $D_{sJ}(2860)$ and $D_{sJ}(3040)$ may be interpreted as the $D_1(2420)K$ and $D^*(2600)K$ bound states, respectively. Using the heavy quark–diquark symmetry, further predict a bound state of the kaon and the doubly-charmed baryon $\overline{\Xi}_{cc}(3520)$ with a mass of 3956 ± 20 MeV.

It is important for any identification of the nature of a hadron to reproduce not only its mass, but also its decay patterns. And it is the latter that can be used to distinguish various models producing similar masses. The decays of $D_{sJ}(2860)$ and $D_{sJ}(3040)$ are dominated by the two-body decays occurring through the rescattering processes $D_1(2420)K \to D^{(*)}K$ and $D^*(2600)K \to D^*K$, respectively. Utilizing heavy quark spin symmetry, we get a parameter-free prediction for the ratio defined in Eq. (1),

$$R_{D_{sJ}(2860)} = 2\frac{M_{D^*}}{M_D}\left|\frac{\vec{k}_{D^*}}{\vec{k}_D}\right|^3 = 1.23. \quad (3)$$

The agreement with the measured value 1.10 ± 0.24 is remarkable. Furthermore, the helicity angular distribution for the sequential process $D_{sJ}(2860) \to D^*K \to D\pi K$ also agrees with the observation [3].

Assuming the decay widths of these kaonic bound states are exhausted by two-body decays, ratios of the total widths can be predicted based on spin symmetry. At leading order, we obtain $\Gamma_{D^*_{s2}(2910)}/\Gamma_{D_{sJ}(2860)} \simeq 0.2$ and $\Gamma_{D^*_{s0}(2985)}/\Gamma_{D_{sJ}(3040)} < 1$. Thus we have $\Gamma_{D^*_{s2}(2910)} \sim 10$ MeV.

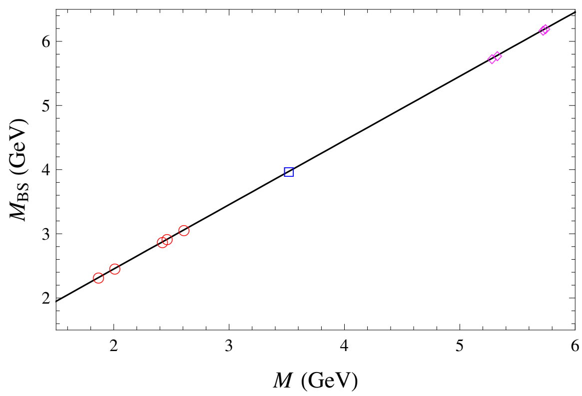

Figure 1: Trajectory of the masses of the generated kaonic bound states obtained with $\mu = 1$ GeV. The charmed, bottom mesons, and doubly charm baryon are labeled by circles, diamonds, and square, respectively.

For a potential use in the future, it might be useful to give a general expression for the masses of such kaonic bound states even approximately. For $\mu = 1$ GeV, a linear expression

$$M_{BS} = 1.002M + 0.450 \text{ GeV}, \quad (4)$$

where M is the mass of the scattered heavy meson or doubly-heavy baryon, covers a range from the charmed mesons to the doubly bottom baryons, see Fig. 1 for the trajectory.

Given the small widths of the $D_1(2420)$ and $D_2(2460)$, the predictions for the $D_{sJ}(2860)$ and $D^*_{s2}(2910)$ should be rather robust. For the $D_{sJ}(2860)$, we expect that an inclusion of the inelastic channels $D^{(*)}K$ and $D_s^{(*)}\eta$ would not change the results much, because these channels are in a P-wave, and so is of higher order compared to the D_1K and $D_{s1}\eta$.

Similar discussion also applies for their bottom cousins. The results for the $D(2550)K$ and $D^*(2600)K$ are of more uncertainty because the $D(2550)$ and $D^*(2600)$ are larger, and also more inelastic channels can couple even in an S-wave. Nevertheless, the $D^*(2600)K$ bound state picture allows the decay of $D_{sJ}(3040)$ into $D_s\omega$ which is highly suppressed were it a $c\bar{s}$ meson due to the OZI rule. We therefore urge the experimentalists to search for the $D^*_{s2}(2910)$ in the D^*K channel and the $D_{sJ}(3040)$ in the $D_s\omega$ channel.

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