P-WAVE CHARM MESONS AS A WINDOW TO THE $D_{sJ}$ STATES

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In my talk I discussed the properties of the newly discovered $D_{sJ}^*(2317)$, $D_{sJ}(2460)$, $X(3872)$, and SELEX $D_{sJ}^*(2632)$ states and suggested experimental measurements that can shed light on them. In this writeup I concentrate on an important facet of understanding the $D_{sJ}$ states, the properties of the closely related $D_0^*$ and $D_1'$ states. These states are well described as the broad, $j = 1/2$ non-strange charmed $P$-wave mesons.

Keywords: Charm Mesons; Charm-strange mesons; quark model.

1. Introduction

The last sixteen months has seen the discovery of the $D_{sJ}^*(2317)$, $D_{sJ}(2460)$, $X(3872)$, and $D_{sJ}^*(2632)$ states. All of these states have properties significantly different from what was predicted beforehand for conventional $q\bar{q}$ states. This has led to considerable theoretical speculation that these states may be something new such as multiquark states or meson-molecules. Another point of view is that conventional $q\bar{q}$ explanations cannot yet be ruled out and there are diagnostic tests that should be applied to understand the nature of these newly discovered states. In my talk I discussed the $q\bar{q}$ possibilities for these new states and the quark model predictions that can be used to test them. Due to length restrictions I will restrict this writeup to new results on the $D_{sJ}^*$, $D_1'$, and $D_{sJ}$ states and refer the interested reader to published work on the $X(3872)$ and SELEX $D_{sJ}^+(2632)$ states.

2. The $D_{sJ}$ States and Their Nonstrange Partners

The four $L = 1$ $P$-wave mesons can be grouped into two doublets characterized by the angular momentum of the light quark: $j = 3/2, 1/2$. The $j = 3/2 c\bar{s}$ states were predicted to be relatively narrow and are identified with the $D_{s1}(2536)$ and $D_{s2}(2573)$ states while the $D_{s0}^*$ and $D_{s1}'$ states were expected to have large $S$-wave widths decaying to $DK$ and $D^*K$ respectively. Quite unexpectedly the Babar$^{11}$ and CLEO$^{12}$ collaborations discovered two charm-strange mesons in $B$-decay, decaying to $D_s^+\pi^0$ and $D_s^{*+}\pi^0$ which were below the $DK$ and $D^*K$ threshold respectively. Virtually all the theoretical effort has concentrated on these states$^{8}$.

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However, their nonstrange partners can also hold important clues to the puzzle but have received almost no attention.

The measured properties of the $L = 1$ charmed mesons are summarized in Table 1 along with quark model predictions. The quark model gives a $P$-wave cog that is $\sim 40$ MeV too high but the splittings are in very good agreement with the measured masses. The width predictions are given for the pseudoscalar emission model with the flux-tube model giving qualitatively similar results. We note that Belle and FOCUS measure $\Gamma(D^*_0) = 37^{+4}_{-5}$ MeV and $\Gamma(D_0^0) = 23^{+7}_{-5}$ MeV which are slightly larger than the PDG values. They attribute the difference from older results to taking into account interference with the broader $D$ states. Overall the agreement between theory and experiment is quite good.

Radiative transitions probe the internal structure of hadrons. Table 2 gives the quark model predictions for $E1$ radiative transitions between the $1P$ and $1S$ charm mesons. Some of these transitions should be observable. The $D_0^0 \rightarrow D^{*0} \gamma$ and $D_1^0 \rightarrow D^0 \gamma$ transitions are of particular interest since the ratio of these partial widths are a measure of the $3P_1 - 1P_1$ mixing angle in the charm meson sector and a good test of how well the HQL is satisfied.

The overall conclusion is that the quark model describes the $P$-wave charmed mesons quite well and models invoked to describe the $D_{sJ}^+(2317)$ and $D_{sJ}^+(2460)$ states must also explain their non-strange charmed meson partners.

Turning to the $D_{sJ}$ states, the narrow $j = 3/2$ states are identified with the $D_{s1}(2536)$ and $D_{s2}(2573)$ with their observed properties in good agreement with quark model predictions. The $j = 1/2$ states were predicted to be broad and to decay to $DK$ and $D^*K$ and were not previously observed. But the $D_{sJ}^+(2317)$ is below $DK$ threshold and the $D_{sJ}^+(2460)$ is below $D^*K$ threshold so the only allowed strong decay is $D_{sJ}^{(*)} \rightarrow D_s^{(*)} \pi^0$ which violates isospin and is expected to have a small width. As a consequence, the radiative transitions are expected to have large BR’s and are an important diagnostic probe to understand the nature.

### Table 1. Comparison of Quark Model Predictions to Experiment for the $L=1$ Charm Mesons.

| State | Mass (MeV) | Width (MeV) |
|-------|------------|-------------|
|       | Theory$^a$ | Expt        | Theory$^b,7,10$ | Expt |
| $D_2^*$ | 2460 | $2459 \pm 2$ $^c$ | 54 | $23 \pm 5$ $^c$ |
| $D_1$   | 2418 | $2422 \pm 1.8$ $^c$ | 24 | $18.9 \pm 4.6$ $^c$ |
| $D_1'$  | 2428 | $2438 \pm 30$ $^d$ | 250 | $329 \pm 84$ $^d$ |
| $D_0^*$ | 2357 | $2369 \pm 22$ $^e$ | 280 | $274 \pm 32$ $^e$ |

$^a$ The $P$-wave cog was adjusted down 42 MeV.
$^b$ Using the masses from column 2.
$^c$ Particle Data Group.
$^d$ Average of the Belle and CLEO $D_s^0$ measurements.
$^e$ Average of the Belle $D_s^0$ and FOCUS $D_0^0$ and $D_0^{*+}$ measurements.
Table 2. Partial widths and branching ratios for E1 transitions between $1^P$ and $1^S$ charmed mesons. The widths are given in keV unless otherwise noted. The $M_i$ and the total widths used to calculate the BR's are taken from Table 1. The matrix elements are calculated using the wavefunctions of Ref. 9.

| Initial state | Final state | $M_i$ (GeV) | $M_f$ (GeV) | $k$ (MeV) | $(1P|r|nS)$ (GeV$^{-1}$) | Width (keV) | BR |
|---------------|-------------|-------------|-------------|-----------|-------------------------|-------------|----|
| $D_{s1}^{+}$  | $D_{s1}^{+} \gamma$ | 2.459       | 2.010       | 408       | 2.367                   | 57          | 0.25% |
| $D_{s1}^{0}$  | $D_{s1}^{0} \gamma$ | 2.459       | 2.007       | 411       | 2.367                   | 559         | 2.4% |
| $D_{s1}^{-}$  | $D_{s1}^{+} \gamma$ | 2.422       | 2.010       | 377       | 2.367                   | 8.8 $\times$ 10$^{-4}$ | |
|               | $D_{s1}^{+} \gamma$ | 2.422       | 1.869       | 490       | 2.028                   | 58          | 0.3% |
| $D_{s1}^{0}$  | $D_{s1}^{0} \gamma$ | 2.422       | 2.007       | 380       | 2.367                   | 87          | 0.5% |
|               | $D_{s1}^{0} \gamma$ | 2.422       | 1.865       | 493       | 2.028                   | 571         | 3.0% |
| $D_{s1}^{+}$  | $D_{s1}^{+} \gamma$ | 2.428       | 2.010       | 382       | 2.367                   | 37          | 10$^{-4}$ |
|               | $D_{s1}^{+} \gamma$ | 2.428       | 1.869       | 494       | 2.028                   | 15          | 4 $\times$ 10$^{-5}$ |
| $D_{s1}^{0}$  | $D_{s1}^{0} \gamma$ | 2.428       | 2.007       | 385       | 2.367                   | 369         | 0.1% |
|               | $D_{s1}^{0} \gamma$ | 2.428       | 1.865       | 498       | 2.028                   | 144         | 4 $\times$ 10$^{-4}$ |
| $D_{s2}^{+}$  | $D_{s2}^{+} \gamma$ | 2.357       | 2.010       | 321       | 2.345                   | 27          | 10$^{-4}$ |
| $D_{s2}^{0}$  | $D_{s2}^{0} \gamma$ | 2.357       | 2.007       | 324       | 2.345                   | 270         | 0.1% |

of these states. Although there are discrepancies between the quark model predictions and existing measurements they can be accommodated by the uncertainty in theoretical estimates of $\Gamma(D_{s}^{(*)} \rightarrow D_{s}^{(*)} \pi)$ and by adjusting the $3^P_1 - 1^P_1$ mixing angle for the $D_{s1}$ states. As in the case of the $D_1$ states, the radiative transitions to $D_s$ and $D_s^*$ can be used to constrain the $3^P_1 - 1^P_1 (c\bar{s})$ mixing angle.

The problem with the newly found $D_{sJ}$ states are the mass predictions. Once the masses are fixed the narrow widths follow. My view is that the strong coupling to $DK$ (and $D^*K$) is the key to solving this puzzle.

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