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RADIATIVE AND STRONG DECAYS OF D_s-MESONS IN THE HADROGENESIS CONJECTURE

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The recently discovered scalar $D^*_{s0}(2317)$ and axial vector $D^*_{s1}(2460)$ charmed strange mesons are predicted in the hadrogenesis picture. They are generated by coupled-channel dynamics involving the scattering of Goldstone bosons off pseudoscalar and vector $D(D_s)$-meson ground-states. The interaction vertices are given by the leading order chiral Lagrangian and chiral corrections to order Q^2_χ. To assess this dynamical picture further, the radiative and strong decays into the isospin-violating $\pi^0 D_s$ and $\pi^0 D^*_s$ channels are calculated. A consistent picture of these decays emerges when the parameters are chosen in accordance with expectations from the heavy-quark symmetry and large N_c limit of QCD and when light vector mesons are introduced explicitly in the radiative decay processes. More accurate data are needed to predict decay parameters reliably.

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1. Introduction

The purpose of the work [1] summarized in this paper is to study consistently the masses, electromagnetic and strong decays of the scalar $D^*_{s0}(2317)$ and axial vector $D^*_{s1}(2460)$ charmed strange mesons in the hadrogenesis conjecture [2,3,4]. It extends earlier investigations showing that such states exist and can be obtained at their observed masses [5,6,7]. This more complete study of the $D^*_{s0}(2317)$ and $D^*_{s1}(2460)$ mesons is motivated by new experimental constraints on their decay channels, the strong isospin-violating π^0 decay and the radiative decay [8,9]. The upper limits for the $D^*_{s0}(2317)$ and $D^*_{s1}(2460)$ total widths are 3.8 and 3.5 MeV respectively [8]. The constraints available on their decays are [9]

$$\frac{\Gamma\,[D^*_{s0}(2317)\,\rightarrow\,D^*_s(2112)\,\gamma]}{\Gamma\,[D^*_{s0}(2317)\,\rightarrow\,D_s(1968)\,\pi^0]}<\,0.059, \tag{1}$$

$$\frac{\Gamma\,[D^*_{s1}(2460)\,\rightarrow\,D_s(1968)\,\gamma]}{\Gamma\,[D^*_{s1}(2460)\,\rightarrow\,D^*_s(2112)\,\pi^0]}=0.31\pm 0.06, \tag{2}$$

$$\frac{\Gamma\,[D^*_{s1}(2460)\,\rightarrow\,D^*_s(2112)\,\gamma]}{\Gamma\,[D^*_{s1}(2460)\,\rightarrow\,D^*_s(2112)\,\pi^0]}<\,0.16, \tag{3}$$

$$\frac{\Gamma\,[D^*_{s1}(2460)\,\rightarrow\,D^*_{s0}(2317)\,\gamma]}{\Gamma\,[D^*_{s1}(2460)\,\rightarrow\,D^*_s(2112)\,\pi^0]}<\,0.22. \tag{4}$$

The decay probability of the $\mathrm{D}^*_{s1}(2460)$ to the $D_s(1968)\,\gamma$ channel is $(16\pm 7)\%$ and the branching fraction $\mathrm{B}(D^*_{s1}(2460)\;\rightarrow\;D^*_s(2112)\,\pi^0)$ is found to be $(56\pm 22)\%$ [8].

We recall in Section 2 the main assumptions underlying the hadrogenesis conjecture. We outline in Sections 3 and 4 how the strong and radiative decays of the $\mathrm{D}^*_{s0}(2317)$ and $\mathrm{D}^*_{s1}(2460)$ are calculated and mention a few results. We refer to Ref. 1 for a complete presentation of the formalism, a thorough discussion of the numerical results and a comparison of our approach to previous calculations.

2. Hadrogenesis

In the hadrogenesis conjecture [2,3,4,5,6,7,10], the $\mathrm{D}^*_{s0}(2317)$ and $\mathrm{D}^*_{s1}(2460)$ mesons are generated by coupled-channel dynamics. In view of their spin and parity, $J^\pi=0^+$ and $J^\pi=1^+$, these states are constructed through the s-wave scattering of Goldstone bosons off D-meson ground-state triplets. The D-meson ground-state triplet consists either of the pseudoscalars $\{D^0(1864),-D^+(1869),D^+_s(1968)\}$ to build the 0^+ state or of the vectors $\{D^{*0}_\mu(1864),-D^{*+}_\mu(1869),D^{*+}_{s\mu}(2112)\}$ to generate the 1^+ state. For the $\mathrm{D}^*_{s0}(2317)^+$ meson, the calculation involves the ηD^+_s, K^0D^+ and K^+D^0 channels coupled further to the $\pi^0D^+_s$ channel through an isospin-mixing parameter. Analogously we consider for the $\mathrm{D}^*_{s1}(2460)^+$ meson the ηD^{*+}_s, K^0D^{*+}, K^+D^{*0} and $\pi^0D^{*+}_s$ channels.

The interaction between the Goldstone bosons and the scalar D-meson triplet is governed by the leading order chiral Lagrangian density [6,7]

$$\begin{aligned}\mathcal{L}=&\,\frac{1}{4}\,\mathrm{tr}\,(\partial_\mu\Phi)\,(\partial^\mu\Phi)-\frac{1}{4}\,\mathrm{tr}\,\chi_0\,\Phi^2+\,(\partial_\mu\mathrm{D})\,(\partial^\mu\bar{\mathrm{D}})-\mathrm{D}\,\mathrm{M}^2_{0^-}\,\bar{\mathrm{D}}\\ &+\frac{1}{8\,f^2}\Big\{(\partial^\mu D)\;[\Phi,(\partial_\mu\Phi)]_-\,\bar{D}-D\;[\Phi,(\partial_\mu\Phi)]_-\,(\partial^\mu\bar{D})\Big\}\,,\end{aligned} \tag{5}$$

where Φ and D are the pseudoscalar octet and triplet fields. We use the notation $\bar{D}=D^\dagger$. The value of the octet meson decay constant f is taken to be $f=90$ MeV [4]. The ground-state scalar D-meson mass matrix is denoted by M_{0^-}. The mass term of the Goldstone bosons is proportional to the quark-mass matrix χ_0.

An expression similar to (5) is derived for the interaction between the Goldstone bosons and the vector D-meson triplet,

$$\mathcal{L} = -(\partial_\mu D^{\mu\alpha})\,(\partial^\nu \bar{D}_{\nu\alpha}) + \frac{1}{2}\,D^{\mu\alpha}\,M_{1^-}^2\,\bar{D}_{\mu\alpha} - \frac{1}{8\,f^2}\Big\{(\partial^\nu D_{\nu\alpha})\;[\Phi,(\partial_\mu\Phi)]_-\,\bar{D}^{\mu\alpha} - D_{\nu\alpha}\;[\Phi,(\partial_\nu\Phi)]_-\,(\partial_\mu\bar{D}^{\mu\alpha})\Big\}\,, \qquad (6)$$

where we represent the 1^- D-mesons in terms of antisymmetric tensor fields. This particular representation has the advantage of leading in a transparent manner to gauge-invariant expressions for the radiative processes considered in this work. Using these chiral Lagrangians at leading order, strong attraction is found in both chiral SU(3) antitriplet states (to which the $D^*_{s0}(2317)$and $D^*_{s1}(2460)$ belong) and sextet states [1].

To improve on the leading order calculation, chiral correction terms are included in a systematic way to order Q_χ^2 [7]. They take into account the s- and u-channel exchanges of D-mesons and local counter terms. The corresponding vertices introduce additional coupling constants constrained by data when available, heavy quark symmetry and the large N_c limit of QCD [1].

3. Strong and radiative decays of the $D^*_{s0}(2317)$ and $D^*_{s1}(2460)$

The strong decays of the $D^*_{s0}(2317)$ and $D^*_{s1}(2460)$ into $\pi^0 D_s$ and $\pi^0 D_s^*$ respectively violate the isospin symmetry. The origin of these processes is the difference between the up-quark mass m_u and the down-quark mass m_d. This mass difference induces two kinds of isospin mixing: the $\pi^0\,\eta$ mixing characterized by an angle ϵ (determined to be 0.01 [11]) and the mixing of I=0 and I=1 channels in the $\bar{K}\,D$ system. We emphasize the importance of taking into account both effects consistently [1].

The isospin-violating strong widths of the $D^*_{s0}(2317)$ and $D^*_{s1}(2460)$ mesons are the dominant contributions to their total widths. In our calculation, they are sensitive to both the coupled-channel dynamics and the angle ϵ. We find that the strong widths of the $D^*_{s0}(2317)$ and $D^*_{s1}(2460)$ are comparable and of the order of 140 keV [1]. This is smaller than the experimental upper limits by a factor of the order of 20. More accurate determinations of these widths would clearly be very useful in unraveling the dynamics underlying these isospin-violating decays.

Calculating the radiative decays of the $D^*_{s0}(2317)$ and $D^*_{s1}(2460)$ mesons requires defining the Lagrangian for electromagnetic interactions to chiral order Q_χ^2. We distinguish four contributions. First, we gauge the Lagrangian describing strong interactions. Only the 3-point vertices involved in the chiral correction terms matter. Secondly, we consider terms of chiral order Q_χ^2 proportional to the electromagnetic tensor $F_{\mu\nu}$ and corresponding to 4-point vertices ($D^* D\pi\gamma$ for example). A third kind of terms of chiral order Q_χ^2 and proportional to $F_{\mu\nu}$ describes the anomalous processes induced by 3-point vertices ($D^* D\gamma$) and the magnetic moments of the charmed vector mesons. A fourth set of terms is introduced to investigate the role of light vector mesons in the radiative transitions.

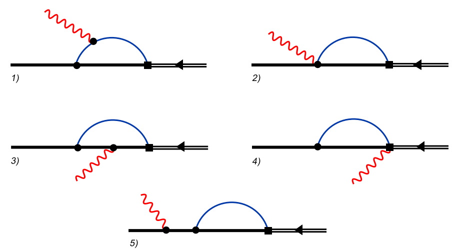

Fig. 1. Diagrams contributing to the decay amplitude of a scalar or axial vector molecule. Solid lines represent the propagation of the pseudoscalar or vector mesons, where the thin lines stand for the light mesons and the thick lines for the heavy mesons. The wavy line is the photon.

We display in Fig. 1 the diagrams contributing to the electromagnetic decay of the $\mathrm{D}^*_{s0}(2317)$ and $\mathrm{D}^*_{s1}(2460)$ mesons in the hadrogenesis picture. The evaluation of these graphs is rather tedious and described in detail in Ref. 1.

The numerical results are linked to specific choices of parameters. We have considered reasonable ranges of values for these quantities and shown that the data available on the radiative decays of the $\mathrm{D}^*_{s0}(2317)$ and $\mathrm{D}^*_{s1}(2460)$ mesons can be understood with natural size parameters.

Specific dynamical effects emerge from our work. We have shown that full relativistic loop computations induce significant deviations from heavy-quark symmetry as expected from the semi-heavy character of the charm-quark mass. We find that the $\eta\, D_s$ and $\eta\, D^*_s$ channels play an important role in radiative decays. Because of large cancellations between graphs involving $\eta\, D_s$ and $K D$ channels, we are not able to make definite predictions yet. The investigation of the role of vector mesons indicates that the $K^* D^*$ and ϕD^*_s channels contribute significantly to the $\mathrm{D}^*_{s0}(2317)$ and $\mathrm{D}^*_{s1}(2460)$ radiative decays.

More accurate data and an improved knowledge of the couplings involved in the calculation (through measurements or lattice studies) are needed to make further progress in the dynamical understanding of the structure of the $\mathrm{D}^*_{s0}(2317)$ and $\mathrm{D}^*_{s1}(2460)$ mesons.

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