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Scaling of the $^3P_0$ strength in heavy meson strong decays

J. Segovia, D.R. Entem *, F. Fernández

Grupo de Física Nuclear and IUFFyM, Universidad de Salamanca, E-37008 Salamanca, Spain

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ABSTRACT

The phenomenological $^3P_0$ decay model has been extensively applied to calculate meson strong decays. The strength γ of the decay interaction is regarded as a free flavor independent constant and is fitted to the data. We calculate through the $^3P_0$ model the total strong decay widths of the mesons which belong to charmed, charmed-strange, hidden charm and hidden bottom sectors. The wave function of the mesons involved in the strong decays are given by a constituent quark model that describes well the meson phenomenology from the light to the heavy quark sector. A global fit of the experimental data shows that, contrarily to the usual wisdom, the γ depends on the reduced mass of the quark–antiquark pair in the decaying meson. With this scale-dependent strength γ, we are able to predict the decay width of orbitally excited B mesons not included in the fit.

1. Introduction

Since the discovery in 1974 of the J/ψ and, three years later, the Υ states, charmonia and bottomonia have been throughly studied, and still are a subject of intensive theoretical and experimental research (see for instance Ref. [1]). The fundamental reason is that a nonrelativistic picture seems to hold for them and they constitute the simplest nontrivial system that can be used to test basic properties of QCD in its nonperturbative regime.

In particular, the heavy meson spectra can be reasonably understood in nonrelativistic models with simple or sophisticated versions of the funnel potential, containing a short-range Coulomb-type term coming from one-gluon exchange plus a long-range confining term.

However, meson strong decay is a complex nonperturbative process that has not yet been described from first principles of QCD. This leads a rather poorly understood area of hadronic physics which is a problem because decay widths comprise a large portion of our knowledge of the strong interaction.

Several phenomenological models have been developed to deal with this topic. The most popular are the $^3P_0$ model [2–4] and the flux-tube model [5–7]. Both decay models assume that a quark–antiquark pair is created with vacuum quantum numbers, $J^{PC}=0^{++}$, but the flux-tube model includes the overlaps of the flux-tube of the initial meson with those of the two outgoing mesons.

The $^3P_0$ model was first proposed by Micu [2]. Le Yaouanc et al. applied subsequently this model to meson [3] and baryon [4] open-flavor strong decays in a series of publications in the 1970s. They also evaluated strong decay partial widths of the three charmonium states $\psi(3770)$, $\psi(4040)$ and $\psi(4415)$ within the same model [8,9].

The $^3P_0$ model, which has since been applied extensively to the decays of light mesons and baryons [10], was originally adopted largely due to its success in the prediction of the D/S amplitude ratio in the decay $b_1\to\omega\pi$. Another success of the decay model is that it predicts a zero branching fraction $\mathcal{B}(\pi_2(1670)\to b_1\pi)$ and it is experimentally measured to be $<1.9\times10^{-3}$ at 97.7% confidence level. It would not necessary be negligible in a different decay model.

An important characteristic, apart from its simplicity, is that the model provides the gross features of various transitions with only one parameter, the strength γ of the decay interaction, which is regarded as a free constant and is fitted to the data. It is generally believed that the pair-production strength parameter γ, is roughly flavor-independent for decays involving production of $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$ pairs. As an example, one can mention the work of Ref. [11] where a total of 32 experimentally well-determined decay rates have been fitted using the $^3P_0$ model. The large experimental errors preclude definitive conclusions about the dependence of γ with respect to the flavor sector and the authors followed the convention of using a unique value for the γ parameter. However, it is important to note that only 3 of the total 32 decay modes are referred to the heavy quark sector. They are $D^{*+}\to D^0\pi^+$, $\psi(3770)\to D\bar{D}$ and $D^*_{s2}\to DK+D^*K+D_s\eta$. Strong decay widths of mesons containing b-quark are not treated and the remaining 29 decay modes involve light and strange mesons.

* Corresponding author.
E-mail address: entem@usal.es (D.R. Entem).

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Some attempts have been done to find a possible dependence of the vertex parameter γ. In particular, Bonnaz and Silvestre-Brac has studied 10 different p dependences of the γ parameter, where p is the relative momentum of the created $q\bar{q}$ pair. The model was only applied to mesons involving light quarks. Although some improvement in the description of the data has been found, it depends very crucially from the vertex form which is arbitrary and unconstrained.

Our purpose here is to find a scale dependence of γ from the light to the heavy quark sector using a fit to the decay widths of the mesons which belong to charmed, charmed-strange, hidden charm and hidden bottom sectors calculated with the $^3P_0$ model. Certainly, the theoretical results have some uncertainties coming from the decay model itself in the description of the creation vertex and the wave functions used. Therefore, we expect to reach a global description of the meson strong decays in every sector, not to take into account the details of each decay mode.

The wave functions for the mesons involved in the open-flavor strong decays are the solutions of the Schrödinger equation with the potential model described in Ref. [12] using the Gaussian Expansion Method [13]. The model has recently been applied to mesons containing heavy quarks in Refs. [14–16], where different properties as spectra, strong decays and weak decays, has been successfully explained.

In the Letter we proceed as follows. In Section 2 we review the $^3P_0$ decay model adapted to our formalism. Section 3 is devoted to the parametrization of the strength γ of the decay interaction as a function of the scale. In Section 4 we present our results, comments about them are also included. Finally, we give some remarks and conclusions in Section 5.

2. The $^3P_0$ decay model

2.1. Transition operator

The interaction Hamiltonian involving Dirac quark fields that describes the production process is given by

$$H_I = \sqrt{3} g_s \int d^3x \, \bar{\psi}(\vec{x}) \psi(\vec{x}), \tag{1}$$

where we have introduced for convenience the numerical factor $\sqrt{3}$, which will be canceled with the color factor.

If we write the Dirac fields in second quantization and keep only the contribution of the interaction Hamiltonian which creates a $(\mu\nu)$ quark–antiquark pair, we arrive, after a nonrelativistic reduction, to the following expression for the transition operator

$$\begin{aligned} T = {} & -\sqrt{3} \sum_{\mu,\nu} \int d^3p_\mu \, d^3p_\nu \, \delta^{(3)}(\vec{p}_\mu + \vec{p}_\nu) \frac{g_s}{2m_\mu} \sqrt{2^5\pi} \\ & \times \left[\mathcal{Y}_1\left(\frac{\vec{p}_\mu - \vec{p}_\nu}{2}\right) \otimes \left(\frac{1}{2}\frac{1}{2}\right)1 \right]_0 a^\dagger_\mu(\vec{p}_\mu) b^\dagger_\nu(\vec{p}_\nu), \end{aligned} \tag{2}$$

where μ (ν) are the spin, flavor and color quantum numbers of the created quark (antiquark). The spin of the quark and antiquark is coupled to one. The $\mathcal{Y}_{lm}(\vec{p}) = p^l Y_{lm}(\hat{p})$ is the solid harmonic defined in function of the spherical harmonic.

As in Ref. [17], we fix the relation of g_s with the dimensionless constant giving the strength of the quark–antiquark pair creation from the vacuum as $\gamma = g_s/2m$, being m the mass of the created quark (antiquark).

2.2. Transition amplitude

We are interested on the transition amplitude for the reaction $(\alpha\beta)_A \to (\delta\epsilon)_B + (\lambda\rho)_C$. The meson A is formed by a quark α and antiquark β. At some point it is created a $(\mu\nu)$ quark–antiquark pair. The created $(\mu\nu)$ pair together with the $(\alpha\beta)$ pair in the original meson regroups in the two outgoing mesons via a quark rearrangement process. These final mesons are meson B which is formed by the quark–antiquark pair $(\delta\epsilon)$ and meson C with $(\lambda\rho)$ quark–antiquark pair.

We work in the center-of-mass reference system of meson A, thus we have $\vec{K}_A = \vec{K}_0 = 0$ with $\vec{K}_A$ and $\vec{K}_0$ the total momentum of meson A and of the system BC with respect to a given reference system. We can factorize the matrix element as follow

$$\langle BC|T|A\rangle = \delta^{(3)}(\vec{K}_0) \mathcal{M}_{A\to BC}. \tag{3}$$

The initial state in second quantization is

$$|A\rangle = \int d^3p_\alpha \, d^3p_\beta \, \delta^{(3)}(\vec{K}_A - \vec{P}_A) \phi_A(\vec{p}_A) a^\dagger_\alpha(\vec{p}_\alpha) b^\dagger_\beta(\vec{p}_\beta)|0\rangle, \tag{4}$$

where α (β) are the spin, flavor and color quantum numbers of the quark (antiquark). The wave function $\phi_A(\vec{p}_A)$ denotes a meson A in a color singlet with an isospin I_A with projection M_{I_A}, a total angular momentum J_A with projection M_A, J_A is the coupling of angular momentum L_A and spin S_A. The $\vec{p}_\alpha$ and $\vec{p}_\beta$ are the momentum of quark and antiquark, respectively. The $\vec{P}_A$ and $\vec{p}_A$ are the total and relative momentum of the $(\alpha\beta)$ quark–antiquark pair within the meson A. The final state is more complicated than the initial one because it is a two-meson state. It can be written as

$$\begin{aligned} |BC\rangle = {} & \frac{1}{\sqrt{1+\delta_{BC}}} \int d^3K_B \, d^3K_C \sum_{m,M_{BC}} \langle J_{BC} M_{BC} lm | J_T M_T \rangle \delta^{(3)} \\ & \times (\vec{K} - \vec{K}_0) \delta(k - k_0) \frac{Y_{lm}(\hat{k})}{k} \\ & \times \sum_{M_B, M_C, M_{I_B}, M_{I_C}} \langle J_B M_B J_C M_C | J_{BC} M_{BC} \rangle \\ & \times \langle I_B M_{I_B} I_C M_{I_C} | I_A M_{I_A} \rangle \int d^3p_\delta \, d^3p_\epsilon \, d^3p_\lambda \, d^3p_\rho \\ & \times \delta^{(3)}(\vec{K}_B - \vec{P}_B) \delta^{(3)}(\vec{K}_C - \vec{P}_C) \phi_B(\vec{p}_B) \phi_C(\vec{p}_C) \\ & \times a^\dagger_\delta(\vec{p}_\delta) b^\dagger_\epsilon(\vec{p}_\epsilon) a^\dagger_\lambda(\vec{p}_\lambda) b^\dagger_\rho(\vec{p}_\rho)|0\rangle, \end{aligned} \tag{5}$$

where we have followed the notation of meson A for the mesons B and C. We assume that the final state of mesons B and C is a spherical wave with angular momentum l. The relative and total momentum of mesons B and C are $\vec{k}_0$ and $\vec{K}_0$. The total spin J_{BC} is obtained coupling the total angular momentum of mesons B and C, and J_T is the coupling of J_{BC} and l.

The $^3P_0$ model takes into account only diagrams in which the $(\mu\nu)$ quark–antiquark pair separates into different final mesons. This was originally motivated by the experiment and it is known as the Okubo–Zweig–Iizuka (OZI)-rule [18–20] which tells us that the disconnected diagrams are more suppressed than the connected ones. The diagrams that can contribute to the decay width through the $^3P_0$ model are shown in Fig. 1.

2.3. Decay width

The total width is the sum over the partial widths characterized by the quantum numbers J_{BC} and l

$$\Gamma_{A\to BC} = \sum_{J_{BC},l} \Gamma_{A\to BC}(J_{BC}, l), \tag{6}$$

where

$$\Gamma_{A\to BC}(J_{BC}, l) = 2\pi \int dk_0 \, \delta(E_A - E_{BC}) \left|\mathcal{M}_{A\to BC}(k_0)\right|^2. \tag{7}$$

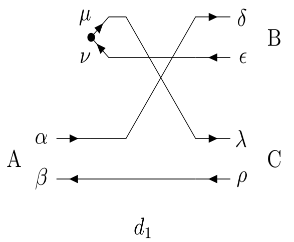

Fig. 1. Diagrams that can contribute to the decay width through the $^3P_0$ model.

Table 1
Meson decay widths which have been taken into account in the fit of the scale-dependent strength, γ. Some properties of these mesons are also shown.

Meson	I	J	P	C	Mass (MeV)	$\Gamma_{\text{Exp.}}$ (MeV)	
$D_1(2420)^{\pm}$	1/2	1	+1	–	2423.4 ± 3.1	25 ± 6	[21]
$D_2^*(2460)^{\pm}$	1/2	2	+1	–	2464.4 ± 1.9	37 ± 6	[21]
$D_{s1}(2536)^{\pm}$	0	1	+1	–	2535.12 ± 0.25	1.03 ± 0.13	[22]
$D_{s2}^*(2575)^{\pm}$	0	2	+1	–	2571.9 ± 0.8	17 ± 4	[21]
$\psi(3770)$	0	1	−1	−1	3778.1 ± 1.2	27.5 ± 0.9	[21]
$\Upsilon(4S)$	0	1	−1	−1	10579.4 ± 1.2	20.5 ± 2.5	[21]

We use relativistic phase space, so

$$\Gamma_{A\to BC}(J_{BC}, l) = 2\pi \frac{E_B(k_0)E_C(k_0)}{m_A k_0} \left|\mathcal{M}_{A\to BC}(k_0)\right|^2, \tag{8}$$

where

$$k_0 = \frac{\sqrt{[m_A^2 - (m_B - m_C)^2][m_A^2 - (m_B + m_C)^2]}}{2m_A}, \tag{9}$$

is the on-shell relative momentum of mesons B and C.

3. Running of the strength γ of the decay interaction

The strength parameter of the $^3P_0$ model shows two different type of dependencies. The first one is the scale with the mass of the pair created through the relationship with the g_s constant, $\gamma = g_s/2m$. As in this work we will study only decays which include the creation of a light quark pair, this dependence will not be used.

However, if g_s is related to fundamental QCD parameters, among them the strong coupling constant, one expects that g_s, and hence γ, depends on some scale defined by the quark sector.

To elucidate the γ dependence on this scale, we calculate through the $^3P_0$ model the total strong decay widths of the mesons which belong to charmed, charmed-strange, hidden charm and hidden bottom sectors. Table 1 shows the experimental data taken for the fit.

In the case of the charmed and charmed-strange sectors, we have considered the total decay widths of the mesons which belong to the $j_q^P = 3/2^+$ doublet predicted by heavy quark symmetry. The reason is that any quark model predicts the doublet $j_q^P = \frac{3}{2}^+$ in reasonable agreement with the experiment. Focusing on the 2^+ meson there are no doubts about its nature and wave function composition. Moreover, in the infinite heavy quark mass limit these states are narrow, and so we expect that the resonance parameters are better determined than other states of the same sector.

For charmonium and bottomonium mesons, we have considered that the best experimental measurement of total decay widths is that of the state immediately above the open-flavor sector. This means the total decay width of the $\psi(3770)$ and $\Upsilon(4S)$ states, respectively.

The decay of $\psi(3770)$ into the DD channel has been widely studied. This channel is the only open threshold for $\psi(3770)$ and therefore its total width should be given almost by the decay into DD. However, during the last years this was not the case and the non-DD contribution to the total decay width was large, 15%. Now, Ref. [21] provides a branching fraction of $\mathcal{B}(\psi(3770) \to DD) = (93^{+8}_{-9})\%$, which is more compatible with the theoretical expectations.

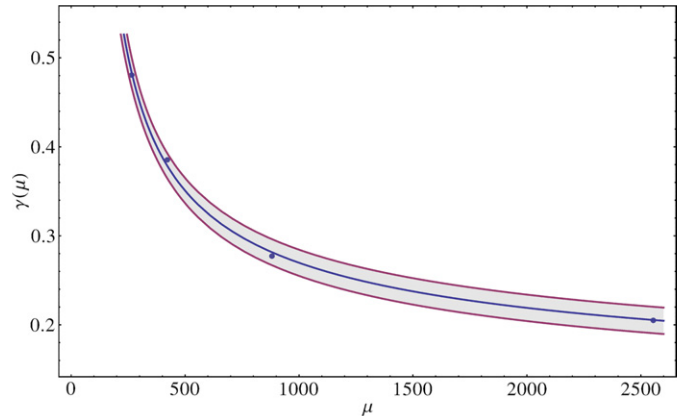

Fig. 2. The scale-dependent strength, γ, in function of the reduced mass of the $q\bar{q}$ pair of the decaying meson, μ. The data points are the value of γ needed to reproduce the meson decay widths shown in Table 1. The solid line is the fit and the shaded area is the confidence interval with 90% confidence level.

The $\Upsilon(4S)$ state is the first one in the bottomonium sector that decays into a pair of B mesons. In fact, the $\Upsilon(4S)$ resonance decays in almost 100% of cases to a BB pair, and this feature is exploited by the B-factories to become an important source of data on heavy hadrons in the last years.

Once the experimental data have been established, we propose a scale-dependent strength γ, given by

$$\gamma(\mu) = \frac{\gamma_0}{\log(\frac{\mu}{\mu_0})}, \tag{10}$$

where μ is the reduced mass of the quark–antiquark in the decaying meson and, $\gamma_0 = 0.81 \pm 0.02$ and $\mu_0 = (49.84 \pm 2.58)$ MeV are parameters determined by a global fit of the total decay widths mentioned above.

Fig. 2 shows the scale-dependent strength γ as a function of the reduced mass of the decaying meson μ. The data points are the value of γ needed to reproduce the meson decay widths shown in Table 1. The solid line is the fit and the shaded area is the confidence interval with 90% confidence level.

For completeness, we show in Table 2 the values of the scale-dependent strength γ in the different flavor sectors following Eq. (10). We also show values of the strength γ taken from the literature.

4. Results

Table 3 shows our results for the total strong decay widths of the mesons which belong to charmed, charmed-strange, hidden charm and hidden bottom sectors. In the case of mesons containing a single c-quark, we have considered the newly observed charmed mesons $D(2550)$, $D^*(2600)$, $D_J(2750)$ and $D_J^*(2760)$, and charmed-strange mesons $D_{s1}^*(2710)$, $D_{sJ}^*(2860)$ and $D_{sJ}(3040)$. Our model predicts as naive $c\bar{c}$ states the $X(4360)$, $X(4640)$ and $X(4660)$ mesons, they are also included in the study of the charmonium sector. The bottomonium states are the usual ones above the BB threshold.

We get a quite reasonable global description of the total decay widths. The detailed analysis of the decay modes of every resonance is beyond the scope of this work, whose main goal is to

Table 2
Values of the scale-dependent strength γ in the different quark sectors following Eq. (10). The reduced mass of the $q\bar{q}$ pair in the decaying meson μ is given in MeV. Different values of the γ strength parameter taken from the literature are also shown for comparison.

	Light mesons			Heavy-light mesons				Heavy mesons		
	$(n\bar{n})$	$(n\bar{s})$	$(s\bar{s})$	$(n\bar{c})$	$(s\bar{c})$	$(n\bar{b})$	$(s\bar{b})$	$(c\bar{c})$	$(c\bar{b})$	$(b\bar{b})$
μ	156.5	200.1	277.5	265.8	422.1	294.9	500.6	881.5	1310.8	2555.0
γ	0.707	0.582	0.471	0.483	0.379	0.455	0.351	0.282	0.247	0.205
γ	0.506 [17] 0.410 [25] 0.615 [27] 0.675 [26] 0.400 [28]	0.506 [17] 0.410 [25] 0.615 [27]	0.625 [23] 0.380 [26] 0.400 [28]		0.500 [11]		0.400 [24]			

Table 3
Strong total decay widths calculated through the $^3P_0$ model of the mesons which belong to charmed, charmed-strange, hidden charm and hidden bottom sectors. The value of the parameter γ in every sector is given by Eq. (10).

Meson	I	J	P	C	n	Mass (MeV)	$\Gamma_{\text{Exp.}}$ (MeV)	[21]	$\Gamma_{\text{The.}}$ (MeV)
$D^*(2010)^\pm$	0.5	1	−1	–	1	2010.28 ± 0.13	$0.096 \pm 0.004 \pm 0.022$		0.036
$D_0^*(2400)^\pm$	0.5	0	+1	–	1	$2403 \pm 14 \pm 35$	$283 \pm 24 \pm 34$		212.01
$D_1(2420)^\pm$	0.5	1	+1	–	1	2423.4 ± 3.1	25 ± 6		25.27
$D_1(2430)^0$	0.5	1	+1	–	2	$2427 \pm 26 \pm 25$	$384^{+107}_{-75} \pm 74$		229.12
$D_2^*(2460)^\pm$	0.5	2	+1	–	1	2464.4 ± 1.9	37 ± 6		64.07
$D(2550)^0$	0.5	0	−1	–	2	$2539.4 \pm 4.5 \pm 6.8$	$130 \pm 12 \pm 13$	[29]	132.07
$D^*(2600)^0$	0.5	1	−1	–	2	$2608.7 \pm 2.4 \pm 2.5$	$93 \pm 6 \pm 13$	[29]	96.91
$D_J(2750)^0$	0.5	$\begin{bmatrix} 2 \\ 3 \end{bmatrix}$	−1	–	1	$2752.4 \pm 1.7 \pm 2.7$	$71 \pm 6 \pm 11$	[29]	$\begin{bmatrix} 229.86 \\ 107.64 \end{bmatrix}$
$D_J^*(2760)^0$	0.5	1	−1	–	3	$2763.3 \pm 2.3 \pm 2.3$	$60.9 \pm 5.1 \pm 3.6$	[29]	338.63
$D_{s1}(2536)^\pm$	0	1	+1	–	1	2535.12 ± 0.25	1.03 ± 0.13	[22]	0.99
$D_{s2}^*(2575)^\pm$	0	2	+1	–	1	2571.9 ± 0.8	17 ± 4		18.67
$D_{s1}^*(2710)^\pm$	0	1	−1	–	2	$2710 \pm 2^{+12}_{-7}$	$149 \pm 7^{+39}_{-52}$	[30]	170.76
$D_{sJ}^*(2860)^\pm$	0	$\begin{bmatrix} 1 \\ 3 \end{bmatrix}$	−1	–	$\begin{bmatrix} 3 \\ 1 \end{bmatrix}$	$2862 \pm 2^{+5}_{-2}$	$48 \pm 3 \pm 6$	[30]	$\begin{bmatrix} 153.19 \\ 85.12 \end{bmatrix}$
$D_{sJ}(3040)^\pm$	0	1	+1	–	$\begin{bmatrix} 3 \\ 4 \end{bmatrix}$	$3044 \pm 8^{+30}_{-5}$	$239 \pm 35^{+46}_{-42}$	[30]	$\begin{bmatrix} 301.52 \\ 432.54 \end{bmatrix}$
$\psi(3770)$	0	1	−1	−1	3	3778.1 ± 1.2	27.5 ± 0.9		26.47
$\psi(4040)$	0	1	−1	−1	4	4039 ± 1	80 ± 10		111.27
$\psi(4160)$	0	1	−1	−1	5	4153 ± 3	103 ± 8		115.95
$X(4360)$	0	1	−1	−1	6	$4361 \pm 9 \pm 9$	$74 \pm 15 \pm 10$	[31]	113.92
$\psi(4415)$	0	1	−1	−1	7	4421 ± 4	62 ± 20		159.02
$X(4640)$	0	1	−1	−1	8	4634^{+8+5}_{-7-8}	92^{+40+10}_{-24-21}	[32]	206.37
$X(4660)$	0	1	−1	−1	9	$4664 \pm 11 \pm 5$	$48 \pm 15 \pm 3$	[31]	135.06
$\Upsilon(4S)$	0	1	−1	−1	6	10579.4 ± 1.2	20.5 ± 2.5		20.59
$\Upsilon(10860)$	0	1	−1	−1	8	10876 ± 11	55 ± 28		27.89
$\Upsilon(11020)$	0	1	−1	−1	10	11019 ± 8	79 ± 16		79.16

establish a scale dependence for γ. However, let us comment in more detail each sector discussing briefly the most significant aspects.

The results predicted by the $^3P_0$ model for the well established charmed mesons are in good agreement with the experimental data except for one case, the total decay width of the D^* meson. The D^* decays only into $D\pi$ channel via strong interaction and it is assumed that the total decay width is given mainly by this decay mode. However, the disagreement may be due to the very small available phase space which enhances possible effects of the final-state interactions.

In Ref. [29] the BaBar Collaboration reported the new charmed states $D(2550)$, $D^*(2600)$, $D_J(2750)$ and $D_J^*(2760)$ in inclusive e^+e^- collisions. The $J^P = 0^-$ is the most plausible assignment for the $D(2550)$ meson, the total width predicted by the $^3P_0$ model with this assignment is in very good agreement with the experimental data. The helicity-angle distribution of $D^*(2600)$ is found to be consistent with $J^P = 1^-$. Moreover, its mass makes it the perfect candidate to be the spin partner of the $D(2550)$ meson. Our prediction of the total decay width as the 2^3S_1 state agrees again with the data. There is a strong discussion in the literature about the possible quantum numbers that could have the mesons $D_J(2750)$ and $D_J^*(2760)$ providing a wide range of assignments. The total strong decay widths of these mesons have been calculated attending to the most plausible assignment coming from our model. While there seems to be a consistent assignment to the $D_J(2750)$ meson, it is not the case for the $D_J^*(2760)$ one.

In Ref. [15] we have considered the coupling between the 1^+ $c\bar{s}$ states and a tetraquark, finding that the $J^P = 1^+$ $D_{s1}(2460)$ has an important non-$q\bar{q}$ contribution whereas the $J^P = 1^+$ $D_{s1}(2536)$ is almost a pure $q\bar{q}$ state. The presence of non-$q\bar{q}$ degrees of freedom in the $J^P = 1^+$ charmed-strange meson sector enhances the $j_q = 3/2$ component of the $D_{s1}(2536)$. This wave function explains most of the experimental data, as shown in Refs. [15,16], and it is the one we use here.

Two new charmed-strange resonances, the $D_{s1}^*(2710)$ and $D_{sJ}^*(2860)$, have been observed by the BaBar Collaboration in both DK and D^*K channels [30]. In the D^*K channel, the BaBar Collaboration have also found evidence for the $D_{sJ}(3040)$, but there is no signal in the DK channel. It is commonly believed that the $D_{s1}^*(2710)$ is the first excitation of the D_s^* meson. With this assignment, the prediction of the $^3P_0$ model is in agreement with the experimental data. In Table 3 we show the total strong decay width of the $D_{sJ}^*(2860)$ as the third excitation of the 1^- meson

Table 4
Some strong decay observables of light mesons calculated through the $^3P_0$ model with the value of the parameter γ given by Eq. (10). The theoretical range on the total decay width of the $f_0(600)$ is obtained moving the mass of the $f_0(600)$ in its experimental range.

Decay mode	Theory	Experiment
$f_0(600) \to \pi\pi$	$\Gamma_{\pi\pi} = (224\text{–}651)$ MeV	$\Gamma_{\text{tot}} = (250\text{–}500)$ MeV
$h_1(1170) \to \rho\pi$	$\Gamma_{\rho\pi} = 619$ MeV	$\Gamma_{\text{tot}} = (360 \pm 40)$ MeV
$f_2(1270) \to \pi\pi$	$\Gamma_{\pi\pi} = 315$ MeV	$\Gamma_{\pi\pi} = (156.9^{+4.0}_{-1.2})$ MeV
$\rho \to \pi\pi$	$\Gamma_{\pi\pi} = 160$ MeV	$\Gamma_{\pi\pi} = (148.1 \pm 0.6)$ MeV
$b_1(1235) \to \omega\pi$	$\Gamma_{\omega\pi} = 158$ MeV	$\Gamma_{\text{tot}} = (142 \pm 9)$ MeV
	$\mathcal{B}((\omega\pi)_{\text{S-wave}}) = 0.76$	–
	$\mathcal{B}((\omega\pi)_{\text{D-wave}}) = 0.24$	–
	$\mathcal{B}((\omega\pi)_{\text{D-wave}})/\mathcal{B}((\omega\pi)_{\text{S-wave}}) = 0.32$	$\mathcal{B}((\omega\pi)_{\text{D-wave}})/\mathcal{B}((\omega\pi)_{\text{S-wave}}) = 0.277 \pm 0.027$
$a_1(1260) \to \rho\pi$	$\Gamma_{\rho\pi} = 837$ MeV	$\Gamma_{\text{tot}} = (250\text{–}600)$ MeV
	$\mathcal{B}((\rho\pi)_{\text{S-wave}}) = 0.91$	$\mathcal{B}((\rho\pi)_{\text{S-wave}}) = 0.6019$
	$\mathcal{B}((\rho\pi)_{\text{D-wave}}) = 0.09$	$\mathcal{B}((\rho\pi)_{\text{D-wave}}) = 0.013 \pm 0.0060 \pm 0.0022$
$a_2(1320) \to \rho\pi$	$\Gamma_{\rho\pi} = 255$ MeV	–
$a_2(1320) \to \eta\pi$	$\Gamma_{\eta\pi} = 69$ MeV	$\Gamma_{\eta\pi} = (18.5 \pm 3.0)$ MeV
$a_2(1320) \to \eta'\pi$	$\Gamma_{\eta'\pi} = 12$ MeV	$\Gamma_{\eta'\pi} = (0.59 \pm 0.10)$ MeV

and as the ground state of the 3^- meson. The comparison between experimental data and our results favors the $n\,J^P = 1\,3^-$ assignment. The mean $2P$ multiplet mass is predicted in our model to be near the mass of the $D_{sJ}(3040)$ resonance. The only decay mode in which $D_{sJ}(3040)$ has been seen until now is the D^*K, and so the most possible assignment is that the $D_{sJ}(3040)$ meson being the next excitation in the 1^+ channel. Table 3 shows our prediction of the $D_{sJ}(3040)$ decay width as the $n\,J^P = 3\,1^+$ or $4\,1^+$ state. Both are large but compatible with the experimental data.

From an experimental point of view there are a few data in the open-charm decays of the 1^{--} $c\bar{c}$ resonances. The main experimental data are the resonance parameters, mass and total decay width, of the excited ψ states fitting the R value measured in the relevant energy region. One can see that the general trend of the total decay widths is well reproduced. There are two particular cases in which the theoretical results exceed the experimental one. The first case is the $\psi(4415)$ where we predict a total width of 159 MeV, while the PDG [21] average value is 62 ± 20 MeV. However one should mention that the experimental data are clustered around two values (~ 100 MeV and ~ 50 MeV) corresponding the lower one to very old measurements. If we compare our result with the recent experimental data reported by Seth et al. [33] ($\Gamma = 119 \pm 16$ MeV), they are more compatible. The second result which disagrees with the experimental data is the corresponding to the pair of states in the vicinity of 4.6 GeV. Both widths are larger than the experimental results. The smallest total width of the $X(4660)$ favors the 4^3D_1 option for this state although interference between the two states can be the origin of the small experimental width.

We obtain a very good agreement between experimental and theoretical total decay widths in the bottomonium sector. The most significant disagreement is found for the $\Upsilon(5S)$ state, note however the large error in the experimental data.

To give a more quantitative measure of the agreement with the data we have perform a χ^2/dof calculation for the results shown in Table 3. If we include all the data we obtain $\chi^2/dof = 101.6$. The strong disagreement is mainly due to the $D_J^*(2760)^0$. If we remove the states whose quantum numbers are not given in the PDG, namely, the $D^*(2600)^0$, $D_J(2750)^0$, $D_J^*(2760)^0$, $D_{sJ}^*(2860)^{+-}$, $D_{sJ}(3040)^{+-}$ and $X(4640)$, the value is reduce to $\chi^2/dof = 6.8$ which is a reasonable value considering the simplicity of the $^3P_0$ model.

Finally, one may wonder what happens in other sectors in which the fit has not been carried out. The question may be more obvious in the light quark sector where the $^3P_0$ model has been extensively used with different values of γ. We do not expect to accurately describe the strong decays of light mesons, but it would be an achievement of the parametrization to obtain light meson widths on the order of the experimental ones. Table 4 shows the theoretical results for some decay modes in the light quark sector and compares with the available experimental data. There are cases in which the agreement is evident, but others do not quite agree with the data. We obtain always the order of magnitude of the total decay widths.

Table 5
Open-flavor strong decay widths, in MeV, of the $B_1(5721)$ and $B_2^*(5747)$ mesons calculated through the $^3P_0$ model with the value of the parameter γ given by Eq. (10).

Meson	Decay mode	$\Gamma_{\text{The.}}$ (MeV)	$\Gamma_{\text{Exp.}}$ (MeV)
$B_1(5721)^0$	$B^{*0}\pi^0$	6.8	
	$B^{*+}\pi^-$	13.6	
	total	20.4	$20.4 \pm 4.5 \pm 9.6$
$B_2(5747)^0$	$B^0\pi^0$	5.7	
	$B^+\pi^-$	11.3	
	$B^{*0}\pi^0$	5.3	
	$B^{*+}\pi^-$	10.6	
	total	32.9	$22.7 \pm 5.0 \pm 10.7$

Another sector not included in the fit is the open-bottom sector. Although the experimental data are scarce, we can focus on the orbitally excited B mesons which has been recently measured by the D0 and CDF Collaborations. There are two well established states, the $B_1(5721)$ and $B_2^*(5747)$ mesons. The CDF Collaboration has reported the width of the $B_2^*(5747)$ and from this one, the width of the $B_1(5721)$ can be estimated using the result of Ref. [34]. In Table 5 we show the predicted widths for these states. One can see a good agreement with the experimental data despite of the fact that the expression for the γ running has not been fitted in this sector. Moreover, as the reduced mass in the B meson is closer to that of the light meson than to that of the heavy meson, this data cannot be reproduced if we use a γ value which fits the bottomonium decays. Although it is independent of γ the ratio $\mathcal{R} = \frac{\mathcal{B}(B_2^* \to B^*\pi)}{\mathcal{B}(B_2^* \to B^{(*)}\pi)} = 0.475 \pm 0.095 \pm 0.069$ gives 0.49, in excellent agreement with the data.

5. Conclusions

We propose a scale-dependent strength γ of the phenomenological $^3P_0$ model as a function of the reduced mass of the quark–antiquark pair of the decaying meson to achieve a global description of the meson strong decays. The dependence of γ has been taken as logarithmically in the reduced mass.

To do that we have performed a calculation of the total strong decay widths of the mesons which belong to charmed, charmed-strange, hidden charm and hidden bottom sectors. The wave functions for the mesons involved in the open-flavor strong decays are given by the potential model described in Ref. [12] which has been successfully applied to hadron phenomenology and reactions.

The results predicted by the $^3P_0$ model with the suggested running of the γ parameter are in a global agreement with the experimental data, being remarkable in most of the cases studied. For mesons containing a single c-quark, we have considered the newly observed charmed mesons ($D(2550)$, $D^*(2600)$, $D_J(2750)$ and $D_J^*(2760)$) and charmed-strange mesons ($D_{s1}^*(2710)$, $D_{sJ}^*(2860)$ and $D_{sJ}(3040)$). In the charmonium sector, possible XYZ assignments have been considered. We obtain good agreement between theoretical and experimental decay widths for the Υ states which are above the open-bottom threshold.

For completeness, we provide some predictions in other sectors in which the fit has not been carried out. The light quark sector shows that our parametrization is not so far of the real picture. The predictions in the open-bottom sector where the reduced mass in the B meson is closer to that of the light meson are in very good agreement with the available experimental data.

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