Decay properties of D and D_s mesons in coulomb plus power potential (CPP_ν)

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Abstract The decay properties of the D and D_s mesons are computed in a nonrelativistic phenomenological quark-antiquark potential of the type $V(r) = -\frac{4}{3}\frac{\alpha_s}{r} + Ar^\nu$ with different choices of ν. Numerical method to solve the Schrödinger equation has been used to obtain the spectroscopy of $q\bar{Q}$ mesons. The numerically obtained radial solutions are employed to obtain the decay constant and leptonic decay widths. It has been observed that predictions of the ground state masses and the decay widths are consistent with other model predictions as well as with the known experimental values.

Key words open charm mesons, potential models, leptonic decay widths

PACS 12.39Jh, 12.40Yx, 13.20Gd

1 Introduction

Recently, the remarkable progress at the experimental side for the study of hadrons has opened up new challenges in the theoretical understanding of light-heavy flavour hadrons [1–5]. The existing results on excited heavy-light mesons are therefore partially inconclusive, and even contradictory in several cases. In this paper, we make an attempt to study properties like mass spectrum, decay constants and other decay properties of the open charm mesons (D, D_s) in the frame work of the nonrelativistic potential model.

2 Nonrelativistic treatment for heavy flavour mesons using CPP_ν

In general, properties of heavy flavour mesons have been studied based on potential models in the frame work of relativistic as well as nonrelativistic quantum mechanics. For the present study of charm meson bound states, we consider a nonrelativistic Hamiltonian given by [6–9]

$$H = M + \frac{p^2}{2M_1} - \frac{4}{3}\frac{\alpha_s}{r} + Ar^\nu \quad (1)$$

here, $M = m_1 + m_2$ and

$$M_1 = \frac{m_1\ m_2}{m_1 + m_2}.$$

For computing the mass difference between different degenerate meson states, we consider the spin dependent part of the usual one gluon exchange potential (OGEP) given in [8, 10–12]. We employ the numerical approach as given by [13] to find the eigen values and radial wave functions of the respective Schrödinger equation. The potential parameter A, is made to vary with ν, keeping the quark mass parameter fixed for each choices of $Q\bar{q}$ system. It is observed that the hyperfine splitting of the 1^3S_1 and 1^1S_0 states are very sensitive to the choices of m_Q and A. The most suitable values of the quark mass parameter are found to be $m_c = 1.28$ GeV, $m_d = 0.35$ GeV and $m_s = 0.500$ GeV for our present study. The computed ground state masses of $c\bar{q}$ are listed in Table 1 in the case of D and D_s mesons. The available experimental values as well as other model predictions are also listed for comparison.

Received 19 January 2010
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Table 1. Mass spectra (in GeV) of D meson.

state	potential index ν								Expt.	RQM[1]	RQM	BSU[2]
	0.1	0.7	0.8	0.9	1.0	1.1	1.3	1.5	[1]	[2]	[3]	[4]
$D(1^3S_1)$	1.985	2.007	2.010	2.013	2.015	2.018	2.021	2.025	2.010	2.009	2.005	2.006
$D(1^1S_0)$	1.932	1.864	1.855	1.848	1.841	1.834	1.823	1.813	1.869	1.875	1.868	1.874
$Ds(1^3S_1)$	2.086	2.102	2.104	2.106	2.108	2.109	2.112	2.114	2.112	2.111	2.113	2.108
$Ds(1^1S_0)$	2.047	1.998	1.992	1.987	1.982	1.977	1.969	1.962	1.968	1.981	1.965	1.975

1 RQM: Relativistic Quark Model. 2 BSU: Blankenbecler-Suger Equation.

3 The decay constants of the D, D_s mesons

The decay constants of mesons are important parameters in the study of leptonic or non-leptonic weak decay processes and it is given by [7, 8, 14],

$$f_P^2 = \frac{3\,|R_P(0)|^2}{\pi M_P}. \tag{2}$$

We re-examine the predictions of the decay constants f_P under different potential schemes by the choices of different ν.

4 Inclusive semileptonic decay of open charm flavour mesons

The decay width and branching ratio for the $\Gamma(D\to \bar{K}^0+e^++\nu_e)$ and $\Gamma(D_s\to \phi+l^++\nu_l)$ mesons are calculated using the expression given by [15–17],

$$\Gamma_{sl}(D) = \frac{G_F^2 m_c^5}{192\pi^3}(|V_{cs}|^2+|V_{cd}|^2)\left[f(x)-\frac{\alpha_s}{\pi}g(x)\right], \tag{3}$$

$$\Gamma_{sl}(D_s) = \frac{G_F^2 m_c^5}{192\pi^3}|V_{cs}|^2\left[f(x)-\frac{\alpha_s}{\pi}g(x)\right], \tag{4}$$

where $f(x)=1-8x+8x^3-x^4-12x^2\log x$, and the analytic expression of the function $g(x)$ is given by [15] $g(x)=-15.28x^6+48.68x^5-60.06x^4+35.3x^3-8.11x^2-1.97x+2.41$. Here, the parameter x is computed as $x=m_s^2/(m_c^{\rm eff})^2$. Generally, for the calculation of the semileptonic decay of the heavy flavour mesons, the m_s is taken as the model mass parameters coming from the fitting of its mass spectrum. However, taking into account of the binding energy effects of the decaying heavy quark within the potential confinement scheme, we consider the decaying heavy quark mass as the effective mass of the quarks, $m_q^{\rm eff}$. And, we define the effective masses of the quarks in the $Q\bar{q}$ system as

$$m_Q^{\rm eff} = m_Q\left(1+\frac{\langle E_{\rm bind}\rangle}{m_Q+m_{\bar{q}}}\right);$$

$$m_{\bar{q}}^{\rm eff} = m_{\bar{q}}\left(1+\frac{\langle E_{\rm bind}\rangle}{m_Q+m_{\bar{q}}}\right)$$

to account for its bound state effects. The binding effect has been calculated as $\langle E_{\rm bind}\rangle = M_{Q\bar{q}}-(m_Q+m_{\bar{q}})$, where m_Q and $m_{\bar{q}}$ are the model mass parameters employed in its spectroscopic study and $M_{Q\bar{q}}$ is the mass of the mesonic state.

From the computed inclusive semileptonic decay widths, the Branching ratio of D_q mesons are obtained using relation, $BR = \Gamma_{sl}\times\tau$. The Lifetime of these mesons ($\tau_D = 1.04$ ps^{-1} and $\tau_{D_s} = 0.5$ ps^{-1}) are obtained from the world average value reported by Particle Data Group (PDG-2008) [1]. The computed results of D and D_s mesons are listed in Table: 2. Our results are found to be in agreement with experimental results at lower potential indexes $\nu\approx 0.1$ to 0.5, which in consistent with the agreement observed for their spectroscopy.

Table 2. The inclusive semileptonic BR of $D\to\bar{K}^0+e^++\nu_e$ and $D_s\to\phi+l^++\nu_l$ states in %.

$CPP_\nu\to$	0.1	0.7	0.8	0.9	1.0	1.1	1.3	1.5	Expt.[1]
BR_D	7.4	5.6	5.4	5.3	5.1	5.0	4.7	4.5	8.6±0.5
BR_{D_s}	2.77	2.29	2.24	2.19	2.15	2.11	2.04	1.98	2.36±0.26

5 Leptonic decay of the open heavy flavour mesons

The total leptonic width of $D_q(q=d,s)$ mesons are given by [18]

$$\Gamma(D_q^+\to l^+\nu_l) = \frac{G_F^2}{8\pi}f_{D_q}^2|V_{cq}|^2 m_l^2\left(1-\frac{m_l^2}{M_{D_q}^2}\right)^2 M_{D_q}. \tag{5}$$

These transitions are helicity suppressed . The leptonic widths of the charged D and D_s (1^1S_0 state) mesons are obtained using Eqn. 5 employing the predicted values of the pseudoscalar decay constants f_D and f_{D_s} along with the masses of the M_D and M_{D_s} obtained from the CPP_ν model. The leptonic widths for separate lepton channel by the choice of $m_{l=\tau,\mu,e}$ are computed. The present results as tabulated in Table 3 along with the computed f_p values. Our results are found to be in accordance with the known experimental values.

Table 3. Psedoscalar f_P decay constant and the leptonic BR of D and D_s mesons.

CPP_ν	D				D_s			
	f_P MeV	BR_τ $\times10^{-3}$	BR_μ $\times10^{-4}$	BR_e $\times10^{-8}$	f_P MeV	BR_τ $\times10^{-2}$	BR_μ $\times10^{-3}$	BR_e $\times10^{-7}$
0.1	154	1.5	2.2	0.5	169	4.3	2.5	0.6
0.5	227	1.6	4.7	1.1	249	7.4	5.4	1.3
0.7	248	1.3	5.6	1.3	273	8	6.4	1.5
1.0	272	0.9	6.6	1.5	299	8.4	7.7	1.8
1.1	278	0.7	6.9	1.6	306	8.4	8	1.9
1.3	289	0.5	7.3	1.7	318	8.4	8.6	2
Expt.[1]		< 2.1	4.4±0.7			6.6±0.6	6.2±0.6	
RQM[5]	234				268			
BS[19, 20]	230±25				248±27			

6 Result and discussions

The spectroscopic results (masses and wave functions) obtained for open charm (D, D_s) mesons with different choice of the confining potential index ν from 0.1 to 1.3 are tabulated along with other relativistic quark model predictions and with the known experimental states.

The semileptonic branching ratios of D and D_s mesons computed with $\nu < 0.7$ are in agreement with their respective experimental values.

Our results for f_P in the potential index ranging from 0.5 to 1.5 are fairly close to the known theoretical prediction as seen from Tables 3. CLEO has reported the first significant measurement of $f_{D+} = 222.6 \pm 16.7$ MeV [21] which is close to our predicted value of 227 MeV at $\nu = 0.5$. The accuracy of the previous world average has been improved by BABAR with $f_{Ds} = 283 \pm 17$ MeV [22] which falls within the range of values predicted here for the potential index $0.7 < \nu < 1.0$.

The leptonic decay branching ratios of D and D_s systems studied here are in accordance with the experimental values. Present study shows the importance of interquark potential in the decay properties of the open charm mesons demonstrated through the present study using the CPP_ν model. Probably, future high luminosity better statistics and high confidence level data sets will be able to provide more light on the spectroscopy and decay properties of these open charm mesons.

Part of this work is done with a financial support from DST, Government of India, under a Major Research Project SR/S2/HEP-20/2006.

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