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S-WAVE MASSES AND DECAY PROPERTIES OF D AND D_S MESONS

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ABSTRACT

Mass spectra and decay properties of D and D_s mesons are investigated in the frame work of a relativistic phenomenological quark model with a confinement potential of the type $V(r) = -\frac{\alpha_c}{r} + Ar^{\nu}$, with ν varying from 0.5 to 2.5. Apart the mass spectra, the decay constants ($f_{P/V}$) and the leptonic branching fractions are calculated in this paper with different choices of ν in the range 0.5 to 2.5. Our predictions are compared with other theoretical models and experimental results.

Key words: ***mass spectrum, decay constant, branching ratio, potential model.***

INTRODUCTION

Many experimental facilities such as FOCUS (E831) at Fermilab, BELLE and CLEO, are continuously providing huge amount of data in the heavy-light mesonic sector [1 - 3].

The recent observations of the orbital excited states of $c\bar{q}$; $(q = u/d)$ and $c\bar{s}$ mesons in particular have ignited interest in the experimental and theoretical study of charm spectroscopy.

It has long been pointed out that light-heavy mesons mimic the hydrogenic atoms of QCD and represent a unique laboratory to test our understanding of QCD [4, 5]. Theoretically, our knowledge of hadron physics is mainly based on phenomenological quark confinement models [6 - 8], as the hadron domain generally falls in the non-perturbative regime of quantum chromodynamics.

The masses and pseudoscalar decay constants of the heavy-light mesons have also been estimated in the context of many QCD-motivated models. These model predictions cover a wide range of values from one another [9 - 13].

Phenomenologically, it is important to have reliable estimates of the decay constants as they are useful in many weak processes such as quark mixing, CP violation etc.

In this paper, we present the calculations of the mass spectrum of $L = 0$ states of $c\bar{q}$ $(q = u/d)$ and $c\bar{s}$ mesons in the relativistic scheme with confinement potential of the form Coulomb plus power potential, with the power index ν varying from 0.5 to 2.5. The decay constants ($f_{P/V}$) of these mesons and leptonic branching fractions are also computed.

THEORETICAL FRAMEWORK

For the study of the light-heavy bound state systems (D and D_S meson), we treat relativistic motion for both the quark and the antiquark.The Hamiltonian for the case then be written as [14]

$$H = \sqrt{p^2 + m_Q^2} + \sqrt{p^2 + m_{\bar{q}}^2} + V(r) \quad (1)$$

where p is the relative momentum of the quark-antiquark motion and m_Q is the heavy quark mass and $m_{\bar{q}}$ is the light quark mass, $V(r)$ is the quark-antiquark potential given as [15]

$$V(r) = -\frac{\alpha_c}{r} + Ar^{\nu} \quad (2)$$

where A is the potential parameter, $\alpha_c = \frac{4}{3}\alpha_s$; α_s being the strong running coupling constant.

In the limit that the heavy quark mass becomes infinite, the heavy-light meson behaves analogously to the hydrogen atom i.e., the heavier quark does not contribute to the orbital degrees of freedom and the properties of the meson are determined by those of the light quark [1]. Thus, we assume a trial wave function to be the form given by the hydrogenic radial wave function,

$$R_{nl}(r) = \left(\frac{\mu^3(n-l-1)!}{n(n+l)!}\right)^{\frac{1}{2}} (\mu r)^l e^{-\frac{\mu r}{2}} L_{n-l-1}^{2l+1}(\mu r) \quad (3)$$

Here, μ is the variational parameter and L_{n-l-1}^{2l+1} is Laguerre polynomial. For a chosen value of ν, the variational parameter, μ is determined for each state using the virial theorem.

$$\left\langle \frac{p^2}{2m} \right\rangle = \frac{1}{2}\left\langle \frac{dV}{rdr} \right\rangle \quad (4)$$

We find the expectation value of H (Eq. (1)) using the equation

$$H\psi = E\psi \quad (5)$$

As the interaction potential assumed here does not contain the spin dependent part, Eq (5) gives the spin average masses of the system in terms of the power index ν. The experimental spin-averaged mass for the ground state is determined as [16]

$$M_{SA} = M_P + \frac{3}{4}(M_V - M_P) \quad (6)$$

where M_V and M_P are the experimentally measured vector and pseudoscalar meson ground state masses. We fix the parameter *A*, for the chosen value of ν using the experimental spin averaged mass for the ground state. Using this value of *A*, we calculate excited S wave masses of D and D_S mesons and our results are listed in Tables (1) and (2).

The quark mass parameters used for the calculations are $m_q = 0.32$ GeV, $m_{\bar{s}} = 0.42$ GeV, $m_c = 1.31$ GeV, and we have used the strong running coupling constant $\alpha_S = 0.397$ for D and $\alpha_S = 0.34$ for D_S.

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DECAY CONSTANTS

The decay constants of mesons are important parameters in the study of leptonic, non-leptonic weak decay processes. The decay constants of pseudoscalar (f_P) and vector (f_V) mesons are obtained by prarameterizing the matrix elements of weak current between the corresponding mesons and the vacuum as

$$\langle 0|\bar{Q}\gamma^{\mu}Q(k)|P_{\mu}(k)\rangle = if_P k^{\mu} \quad (7)$$

$$\langle 0|\bar{Q}\gamma^{\mu}Q(k)|V(k,\varepsilon)\rangle = f_V M_V \varepsilon^{\mu} \quad (8)$$

where k is meson momentum, ε^{μ} and M_V are the polarization vector and mass of the vector meson. In the relativistic model, the decay constant can be expressed through the meson wave function $\Phi_{P,V}(p)$ in the momentum space as [17].

$$f_{P/V} = \left(\frac{12}{M_{P/V}}\right)^{\frac{1}{2}}\int\frac{d^3p}{(2\pi)^3}\left(\frac{E_Q(p)+m_Q}{2E_Q(p)}\right)^{\frac{1}{2}}\times\left(\frac{E_{\bar{q}}(p)+m_{\bar{q}}}{2E_{\bar{q}}(p)}\right)\times \left\{1+\lambda\frac{p^2}{[E_Q(p)+m_Q][E_{\bar{q}}(p)+m_{\bar{q}}]}\right\}\Phi_{P/V}(p) \quad (9)$$

With $\lambda_p = -1$ and $\lambda_V = -1/3$. In the non-relativistic limit $\frac{p^2}{m^2}\to 0$ it reduces to the well-known relation between $f_{P/V}$ and the ground state wave function at the origin $\psi_{P/V}(0)$, the Van – Royen - Weisskopf formula [18],

$$f^2_{P/V} = \frac{12|\psi_{P/V}(0)|^2}{M_{P/V}} \quad (10)$$

The computed values of f_P and f_V for D and D_s meson using eq (10) are tabulated in Tables (3) and (4) respectively.

Table - 1 S wave Masses of D Meson (in GeV)

v	D							
	States							
	1^1S_0	1^3S_1	2^1S_0	2^3S_1	3^1S_0	3^3S_1	4^1S_0	4^3S_1
0.5	1.914	1.997	2.187	2.208	2.332	2.343	2.440	2.447
0.9	1.874	2.014	2.290	2.341	2.561	2.591	2.784	2.806
1.0	1.865	2.018	2.312	2.371	2.615	2.651	2.870	2.897
1.3	1.841	2.031	2.367	2.452	2.768	2.825	3.133	3.176
1.5	1.827	2.038	2.399	2.502	2.871	2.941	3.323	3.377
1.7	1.815	2.045	2.430	2.548	2.976	3.060	3.527	3.592
1.9	1.805	2.052	2.461	2.594	3.088	3.184	3.752	3.827
2.0	1.800	2.055	2.475	2.616	3.144	3.245	3.868	3.947
2.2	1.790	2.060	2.500	2.653	3.250	3.362	4.097	4.185
2.4	1.784	2.068	2.533	2.698	3.375	3.497	4.366	4.462
2.5	1.780	2.069	2.547	2.713	3.426	3.552	4.484	4.585
Expt. [20]	1.869	2.010						
[21]	1.868	2.005	2.589	2.692	3.141	3.226		
[22]	1.874	2.006	2.540	2.601	2.904	2.947	3.175	3.208

Table - 2 S wave Masses of D_S Meson (in GeV)

v	D_S							
	States							
	1^1S_0	1^3S_1	2^1S_0	2^3S_1	3^1S_0	3^3S_1	4^1S_0	4^3S_1
0.5	2.025	2.094	2.283	2.301	2.424	2.432	2.529	2.534
0.9	1.991	2.108	2.385	2.428	2.646	2.672	2.862	2.880
1.0	1.983	2.111	2.406	2.456	2.696	2.727	2.942	2.964
1.3	1.962	2.121	2.458	2.530	2.836	2.885	3.178	3.215
1.5	1.938	2.133	2.487	2.574	2.925	2.986	3.339	3.387
1.7	1.938	2.133	2.513	2.615	3.012	3.086	3.508	3.566
1.9	1.928	2.139	2.536	2.651	3.098	3.183	3.683	3.751
2.0	1.923	2.141	2.546	2.668	3.141	3.232	3.774	3.847
2.2	1.915	2.146	2.566	2.701	3.226	3.328	3.961	4.043
2.4	1.907	2.151	2.585	2.731	3.312	3.424	4.155	4.246
2.5	1.903	2.153	2.594	2.745	3.355	3.471	4.255	4.349
Expt. [20]	1.968	2.112						
[21]	1.965	2.113	2.700	2.806	3.259	3.345		
[22]	1.975	2.108	2.659	2.722	3.044	3.087	3.331	3.364

Table – 3 Pseudoscalar Decay Constants f_P (in GeV)

v	D				D_S			
	1S	2S	3S	4S	1S	2S	3S	4S
	f_P	f_P	f_P	f_P	f_P	f_P	f_P	f_P
0.5	0.219	0.104	0.071	0.055	0.242	0.116	0.080	0.062
0.9	0.285	0.157	0.115	0.093	0.315	0.176	0.130	0.105
1.0	0.298	0.169	0.126	0.102	0.330	0.189	0.141	0.115
1.3	0.331	0.200	0.152	0.124	0.368	0.225	0.172	0.142
1.5	0.349	0.217	0.166	0.135	0.407	0.245	0.190	0.157
1.7	0.365	0.232	0.177	0.143	0.407	0.263	0.205	0.169
1.9	0.378	0.244	0.186	0.149	0.422	0.278	0.218	0.179
2.0	0.384	0.250	0.190	0.152	0.429	0.285	0.223	0.183
2.2	0.394	0.259	0.196	0.155	0.443	0.298	0.232	0.189
2.4	0.404	0.267	0.201	0.158	0.454	0.308	0.240	0.194
2.5	0.407	0.266	0.202	0.158	0.459	0.313	0.243	0.196
[11]	0.227 [0.5]							
[17]	0.243± 0.025							
[09]	0.230							

Table - 4 Vector Decay Constants f_V (in GeV)

v	D				D_S			
	1S	2S	3S	4S	1S	2S	3S	4S
	f_V	f_V	f_V	f_V	f_V	f_V	f_V	f_V
0.5	0.224	0.104	0.071	0.055	0.246	0.116	0.080	0.062
0.9	0.297	0.159	0.116	0.094	0.326	0.177	0.130	0.106
1.0	0.313	0.171	0.126	0.102	0.342	0.191	0.142	0.116
1.3	0.352	0.204	0.153	0.125	0.385	0.228	0.174	0.143
1.5	0.375	0.222	0.168	0.136	0.431	0.250	0.192	0.158
1.7	0.394	0.238	0.180	0.145	0.431	0.269	0.208	0.171
1.9	0.412	0.252	0.189	0.151	0.451	0.285	0.221	0.180
2.0	0.420	0.257	0.193	0.153	0.460	0.293	0.226	0.184
2.2	0.434	0.267	0.199	0.157	0.476	0.306	0.236	0.191
2.4	0.448	0.277	0.204	0.159	0.492	0.318	0.244	0.196
2.5	0.453	0.276	0.206	0.160	0.499	0.323	0.248	0.198
[11]	0.249 [0.5]							
[17]	0.315							
[09]	0.341± 0.023							

Table - 5 Leptonic Branching Fractions

v	D			D_S		
	$BR_\tau \times 10^{-3}$	$BR_\mu \times 10^{-4}$	$BR_e \times 10^{-8}$	$BR_\tau \times 10^{-2}$	$BR_\mu \times 10^{-3}$	$BR_e \times 10^{-7}$
0.5	0.977	1.803	0.424	6.009	2.662	0.626
0.9	0.861	2.985	0.703	5.223	4.444	1.045
1.0	0.789	3.252	0.766	5.347	4.845	1.140
1.3	0.529	3.962	0.933	5.452	5.946	1.399
1.5	0.368	4.368	1.029	5.190	7.189	1.692
1.7	0.233	4.724	1.113	5.211	7.190	1.692
1.9	0.136	5.047	1.189	4.988	7.717	1.816
2.0	0.096	5.190	1.222	4.862	7.960	1.873
2.2	0.035	5.430	1.279	4.607	8.410	1.979
2.4	0.010	5.686	1.339	4.349	8.818	2.075
2.5	0.002	5.776	1.361	4.223	9.007	2.120
Expt [20]	< 2.1	4.4±0.7		6.6±0.6	6.2±0.6	
[11]		4.7[0.5]	1.1[0.5]	7.4[0.5]	5.4[0.5]	1.3[0.5]

LEPTONIC BRANCHING FRACTIONS

The leptonic branching fractions for $(1^1S_0)D$ and D_s mesons are obtained using the formula

$$BR = \Gamma \times \tau \tag{11}$$

Where Γ is given by Quang Ho-Kim et al. [19]

$$\Gamma(D_q^+ \to l^+ \nu_l) = \frac{G_F^2}{8\pi} f_{D_q}^2 \left|V_{cq}\right|^2 m_l^2 \times \left(1 - \frac{m_l^2}{M_{Dq}^2}\right) M_{D_q}; \quad q = d, s \tag{12}$$

and $\tau_D = 1.04$ ps [18] and $\tau_{D_s} = 1.04$ ps [18]. For the calculation of the branching fractions using the eq. (12) we employ the calculated values of the pseudoscalar decay constants obtained using our model. Results are tabulated in Table (5).

RESULTS AND DISCUSSION

In the present study, our predicted masses for the ground states are in good agreement with the experimental values at $v = 1$ which is strongly favored by the lattice simulations. No experimental results are available for the higher excited states; so it is of least value to compare the few theoretical results which are not in mutual agreement.

The pseudoscalar and vector decay constants are calculated and compared with other models. The estimated values are in reasonable accordance with other theoretical predictions around. $v = 1$

The calculated values of leptonic branching fractions are in agreement with the experimental results which can be readily seen from Table (5).

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