Spectra and decay constants of D and D_s mesons

Nayneshkumar Devlani* and Ajay Kumar Rai†
Applied Physics Department, Sardar Vallabhbhai National Institute of Technology, Ichchhanath, Surat - 395007, INDIA

Introduction

Many recent experiments such as those at Beijing Electron Positron Collider, Cornell Electron Storage Ring etc. have ignited considerable interest in the study of spectroscopy of heavy-light flavored mesons. The masses and decay constants of $c\bar{u}$ and $c\bar{s}$ have been calculated in non-relativistic [1] as well as in relativistic approach [2, 3]. We present here a semi-relativistic approach for calculating the various properties of the $c\bar{u}$ and $c\bar{s}$ mesons.

The Approach

For a heavy-light quark bound system we treat the heavy quark(Q) non-relativistically and the light quark($\bar{q}$) relativistically. The Hamiltonian for such a case is given by [4]

$$H = M_Q + \frac{p_1^2}{2m_Q} + \sqrt{p_2^2 + m_{\bar{q}}^2} + V(r) \quad (1)$$

m_Q and $m_{\bar{q}}$ are the mass parameters of heavy and light quark respectively, p_1 and p_2 are their momenta respectively and $V(r)$ is the quark-antiquark potential. We expand the term under the square root in powers of $1/m^2$ and retain only the first two leading terms. For the potential $V(r)$ we consider here a general power potential with the Coulomb term.

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

where $\alpha_c = (4/3)\alpha_s$, α_s being the strong running coupling constant, A is a model potential parameter and ν is a general power corresponding to the confining part of the potential.

Reducing the two body problem in equivalent one body problem and using the variational approach, assuming a trial radial wave function $R(r, \mu)$ we compute the expectation values of the Hamiltonian given by eq. (1) $\langle H \rangle = E(\mu, \nu)$ with the potential defined by eq. (2). The trial wavefunction is Hydrogenic and has the form

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

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

$$\left\langle \frac{P^2}{2M'} \right\rangle = \frac{1}{2} \left\langle \frac{rdV}{dr} \right\rangle \quad (4)$$

along with these values of μ we fit the value of A for the ground state spin averaged mass for the light heavy mesons(D and D_s) to their experimental values using the expression

$$M_{SA} = M_P + \frac{3}{4}(M_V - M_P) \quad (5)$$

where M_V and M_P are the vector and pseudoscalar meson masses. With these values of μ and A in the wavefunction and potential respectively, we calculate the excited states of D and D_S mesons with different choices of ν. The calculated values are listed for a particular value of ν in table 1.

Listed in table 2. are the decay constants for the vector and pseudoscalar mesons. The decay constants are evaluated using the Van

*Electronic address: nayneshdev@gmail.com
†Electronic address: akr@ashd.svnit.ac.in

TABLE I: Vector and pseudoscalar masses of mesons (in GeV)

System	State	ν	M_P			M_V		
			Present	RQM[2]	Expt.[6]	Present	RQM[2]	Expt.[6]
$c\bar{u}$	1S	1.5	1.889	1.868	1.869	2.003	2.005	2.010
$(D^*,\ D)$	2S	1.5	2.611	2.589		2.673	2.692	
	3S	1.5	3.231	3.141		3.276	3.226	
	4S	1.5	3.804			3.840		
$c\bar{s}$	1S	1.1	2.001	1.965	1.968	2.104	2.113	2.112
$(D_s^*,\ D_s)$	2S	1.1	2.694	2.700		2.742	2.806	
	3S	1.1	3.237	3.259		3.268	3.345	
	4S	1.1	3.712			3.738		

TABLE II: Vector and pseudoscalar decay constants of mesons (in GeV)

System	State	ν	f_P			f_V		
			Present	RQM[3]	BS[7, 8]	Present	RQM[3]	BS[7, 8]
$c\bar{u}$	1S	1.5	0.276	0.234	0.230±25	0.285	0.310	0.340±23
$(D^*,\ D)$	2S	1.5	0.173			0.176		
	3S	1.5	0.134			0.135		
	4S	1.5	0.112			0.112		
$c\bar{s}$	1S	1.1	0.313	0.268	0.248±27	0.322	0.315	0.375±24
$(D_s^*,\ D_s)$	2S	1.1	0.185			0.187		
	3S	1.1	0.138			0.139		
	4S	1.1	0.112			0.112		

Royen-Weisskopff formula [5]

$$f^2_{P/V}(nS) = \frac{3\left|R_{nP/V}(0)^2\right|}{\pi M_{nP/V}} \qquad (6)$$

Conclusion

The spectroscopic results obtained for D , D_s mesons are tabulated. Mentioned also are relativistic quark model and experimental results for comparison. Our predictions of masses for pseudoscalar D meson for the states 1S(1.889 GeV), 2S(2.611 GeV) and 3S(3.231 GeV) are in excellent agreement with others and with experimental results wherever available. The agreement is also good for the vector D meson as can be readily seen from table 1. Mass of pseudoscalar D_s meson for the states 1S(2.001 GeV), 2S(2.694 GeV), 3S(3.237 GeV) is also in reasonable agreement with others. Masses of vector D_s is in fair agreement with others as well as experimental data where available. We have also tabulated the decay constants in table 2. As can be seen from the table 2. our results of the vector and pseudoscalar decay constants are in reasonable agreement with others.

References

[1] Godfrey S *et al.* Phys. Rev. D, **43**, 1679,(1991).

[2] M. Di Pierro *et al.*, Phys. Rev. **D64** , 114004(2001), arXiv:hep-ph/0104208

[3] Ebert D *et al.*, Phys. Lett. **B634**, 214 (2006).

[4] Rai A K,*et al.*, J. Phys. G: Nucl. Part. Phys. **28**, 2275 (2002).

[5] Berezhnoy A V *et al.*, Z. Physik **A336**, 89 (1996).

[6] Amsler C *et al.* (Particle Data Group), Phys, Lett. **B**, 1 (2008).

[7] Wang G L, Phys. Lett. **B633**, 492 (2006).

[8] Cvetic G *et al.* Phys. Lett. **B596**, 84 (2004)