Decay constant and leptonic decay of D_s meson

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Mass spectra and decay properties of D_s meson are studied in nonrelativistic quark-antiquark Cornell potential model with additional spin-spin interaction. The mass spectra is computed by numerically solving Schrödinger equation with the help of three parameters quark masses, confinement strength and spin dependent term. For computation of masses of excited state, spin-spin, spin-orbit and tensor terms of confined one gluon exchange potential is added as a perturbation. Using potential parameters and numerical wave functions, we compute the leptonic decay constants and corresponding leptonic branching fractions are also computed. The computed results of decay constant and leptonic decay for D_s meson are in good agreements with the experimental and other theoretical approches.

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1. Introduction

Charm-stange mesons are one of the ideal tools for the study of physics of weak interaction as well as for testing the standard model of particle physics. Experimentally, many excited states are identified by experimental facilities worldwide and upcoming data is also expected to provide more precise information. On the experimental front, different decay modes of these states including leptonic decays and strong decays have also been observed. In the literature, many theoretical attempts have been reported such as relativistic quark model based on quasipotential approach [1], relativized quark model [2], chiral quark model [3], semi-relativistic potential model [4], harmonic confinement model [5]. In nonrelativistic potential models, there exist forms of quark antiquark potentials such as Cornell potential with the Ritz variational scheme [6, 7]. The present form of potential is employed in quarkonia spectroscopy studies [8].

In the present work, we study the spectroscopy properties of D_s meson such as decay constant and leptonic decay widths. For that, we consider the nonrelativistic approach with the interaction potential of the form Cornell potential. For computation of mass spectra, we numerically solve Schrödinger equation and further utilised for study of leptonic decay constants and leptonic branching fractions. Leptonic decays are of great experimental as well as theoretical interest as they are the ideal candidate for the test of standard model.

2. Methodology

For the computation of the mass spectra of D_s meson, we use phenomenological potential model method which is appropriate one specially for the heavy-light mesons. Bound state of two body system is also described in Bethe-Salpeter formalisum. Here we study the bound state of meson state for that the non-relativistic Hamiltonian is given by

$$H = M + \frac{P^2}{2M_{cm}} + V_{Cornell}(r) + V_{SD}(r), \tag{1}$$

where M = $m_1 + m_2$ and $M_{cm} = \frac{m_1 m_2}{m_1+m_2}$. Here m_1 and m_2 are the masses of quarks, $\vec{P}$ is the relative momentum of the each quark. $V_{Cornell}(r)$ is the quark anti-quark potential of the type Coulomb and linear potential which is given as

$$V_{Cornell}(r) = \frac{-4\alpha_s}{3r} + Ar \tag{2}$$

where, A is confinement strength and α_s is the strong running coupling constant. For computation of masses of higher excited states, we add spin dependent part of confined one gluon exchange potential which includes spin-spin, spin-orbit and tensor term. The spin-spin interaction term gives hyper-fine splitting while spin-orbit and tensor terms gives the fine structure of the meson states. Having determined all the parameters, we compute the mass spectra using the Mathematica notebook [9]. The fitted potential perameters of D_s mesons are given in Table I.

Table 1: Potential Parameters D_s mesons spectroscopy

Meson	A	σ	m_c	m_s	δ^P	δ^V
D_s	0.12	1.3	1.313	0.33	2	8/3

Table 2: Psedoscalar and vector decay constant of D_s Meson (MeV)

State	$1S$	$2S$	State	$1S$	$2S$
f_P	252.16	191.35	f_V	240	179
PDG [10]	249 ± 17	–	PDG [10]	257 ± 17	–
LQCD [11]	260.1 ± 10.8	–	LQCD [12]	311 ± 9	–
CCQM [13]	257.7	–	CCQM [13]	272.1	–

3. Decay properties

3.1 Decay Constant

The leptonic decay constants of D_s meson play very important role in understanding the weak decays. In non relativistic limit the leptonic decay constant of S-wave pseudoscalar and vector mesons are given using Van Royen-Weiskopf formula

$$f^2_{P/V} = \frac{3|R_{nsP/V}(0)|^2}{\pi M_{nsP/V}}\left[1 - \frac{\alpha_s}{\pi}\left(\delta^{P/V} - \frac{m_Q - m_{\bar{Q}}}{m_Q + m_{\bar{Q}}} Log\frac{m_Q}{m_{\bar{Q}}}\right)\right], \tag{3}$$

where $\delta_P = 2$ and $\delta_V = \frac{8}{3}$, m_1 and m_2 are quark masses, $|R_{nsP/V}(0)|$ represents the wave function of S wave at origin for pseudoscalar and vector meson respectively and the bracketed quantity represents the first order radiative correction. The results of the leptonic decay constants are given in Tab. 2.

3.2 leptonic decay

The leptonic decay of open flavour mesons belong to rare decay, they have clear experimental signatures due to the presence of the highly energetic lepton in the final state. A quark anti-quark can decay into lepton pair via exchange of $W^{\pm}$ boson and also the annihilation of lepton pair will produce charged mesons. The leptonic decay width of D_s meson and corresponding to the leptonic branching fraction is computed using the relation

$$\mathcal{B}(D_s^+ \to l^+\nu_l) = \frac{G_F^2}{8\pi} f_{Ds}^2 |v_{cs}|^2 m_l^2 \left(1 - \frac{m_l^2}{M_{Ds}^2}\right)^2 M_{Ds} \times \tau_{Ds}. \tag{4}$$

where, G_f is Fermi coupling constant, τ_{Ds} is life time of D_s meson and V_{cs} is the CKM matrix. All the constants are taken from the particle data group [10]. The leptonic width and branching fraction of the D_s meson is obtained from the above equations. Leptonic branching fractions are computed for all the lepton flavours and given in Tab. 3

Table 3: leptonic Branching fraction Ds Meson

	$\mathcal{B}(D_s^+ \to e^+ V_e)$	$\mathcal{B}(D_s^+ \to \mu^+ V_\mu)$	$\mathcal{B}(D_s^+ \to \tau^+ V_\tau)$
Present	1.184×10^{-7}	5.036×10^{-3}	4.939%
PDG [10]	$< 8.3 \times 10^{-5}$	$(5.56 \pm 0.25) \times 10^{-3}$	5.55 ± 0.24%
RQM [1]	1.40×10^{-7}	5.97×10^{-3}	5.82%
PM [6]	0.94×10^{-7}	4.00×10^{-3}	3.78%
CCQM [14]	1.40×10^{-7}	5.97×10^{-3}	5.82%

4. conclusion

We study the spectroscopic properties of charm-strange meson considering the interaction of the form Cornell potential. We present decay constants for S wave and leptonic branching fractions and compared with the available experimental data as well as different theoretical approaches. Our preliminary analysis shows that our results are consistent with the literature. Further, the detailed analysis of mass spectra and the study of other decay properties are underway.

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