

Spectroscopic study of charm-strange meson in Regge phenomenology

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The current study involved a systematic study of D_s meson through well-known Regge theory, which is a prominent approach in the study of hadron spectra. By assuming the existence of the quasilinear Regge trajectories, numerous relations between Regge slope, intercept, and meson masses have been derived. By employing these obtained relations, the Regge parameters are calculated for the 0^- and 1^- trajectories in the (J, M^2) plane in order to determine the masses of the orbitally excited states. The estimated masses are compared with results from several theoretical approaches as well as the available experimental data. Our mass value estimations are expected to be helpful for future experimental evidences, and we expect more candidates for excited charm-strange mesons to be reported in forthcoming years from the running experimental facilities like LHCb, BABAR, BESIII, etc.

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1. Introduction

Considerable advancements have been made in recent years regarding the investigation of the spectra of open charm mesons. The world wide experimental facilities have revealed an increasing number of higher excitations. In the sector of D_s mesons, the most recent Particle Data Group (PDG) [1] has listed a total of 11 resonances that have been observed experimentally with their respective masses and quantum numbers. The low lying $1S$ states as well as the $1P$ ones; $D_{s0}^*(2317)^\pm$, $D_{s1}(2460)^\pm$, $D_{s1}^*(2536)^\pm$, and $D_{s2}^*(2573)^\pm$ are well established and have confirmed J^P values [1]. Also, two new resonances $D_{s1}(2700)$ and $D_{sJ}(2860)$ observed by BABAR Collaboration in 2006 [2]. After few years, the other experimental facilities confirmed the existence of these two states [3]. In 2014, the LHCb Collaboration detected two resonances $D_{s1}^*(2860)$ and $D_{s3}^*(2860)$ with spin-parity 1^- and 3^- respectively [4]. Recently, a new excited D_s meson state named as $D_{s0}(2590)$ decaying into $D^+K^+\pi^+$ was found by LHCb Collaboration [5]. This state mentioned in PDG with $J^P = 0^-$, needs more confirmation. Various theoretical studies predicted this state as 2^1S_0 . One more higher excited D_s meson $D_{sJ}(3040)^+$ listed in PDG was firstly observed by BABAR Collaboration and further LHCb also observed weak evidence of this state [6]. $D_{sJ}(3040)^+$ still needs more confirmation and awaited the determination of J^P value.

In addition to the experimental advancements, a substantial amount of theoretical research has also been conducted on charm-strange mesons. Various phenomenological approaches has been used to study the D_s meson such as, semirelativistic potential model [7], flux tube model [8], relativistic quark model [9–11], potential model [12, 13], QCD sum rule [14], Regge theory [15] etc. The present work is dedicated to the systematic study of D_s meson. We compute the mass spectra in the realm of Regge phenomenology and assign the possible spin parity quantum numbers to the newly observed resonances. We have derived some general relations in terms of Regge slopes, intercepts, and meson masses from the quasi linear Regge trajectories. These extracted relations have been used to compute the Regge parameters and, further to estimate the excited state masses of D_s meson. The paper is structured as follows: after the brief introduction in Sec. 1, in Sec. 2 we describe the Regge theory and derive various relations to obtain the mass spectra. Sec. 3 is dedicated to our calculated results and discussions about them.

2. Theoretical Framework

The Regge trajectories establish a relationship between the spin and mass of the hadrons, therefore assuming the quasi-linear Regge trajectories, the general relation for Regge trajectories can be expressed as [16–18],

$$J = \beta(0) + \beta' M^2, \quad (1)$$

where $\beta(0)$ and β' represent the intercept and slope of the trajectory, respectively. There are two well-defined relations that relate these Regge parameters for different quark flavors [16, 18, 19]. They are expressed as,

$$\beta_{i\bar{i}}(0) + \beta_{j\bar{j}}(0) = 2a_{i\bar{j}}(0) \quad \text{and} \quad \frac{1}{\beta'_{i\bar{i}}} + \frac{1}{\beta'_{j\bar{j}}} = \frac{2}{\beta'_{i\bar{j}}}, \quad (2)$$

where i and j represent quark flavours. By combining the Eqs. (1) and (2) and solving the quadratic equation yield two pairs of solutions as,

$$\frac{\beta'_{j\bar{j}}}{\beta'_{i\bar{i}}} = \frac{1}{2M_{j\bar{j}}^2} \times [(4M_{i\bar{j}}^2 - M_{i\bar{i}}^2 - M_{j\bar{j}}^2) \pm \sqrt{(4M_{i\bar{j}}^2 - M_{i\bar{i}}^2 - M_{j\bar{j}}^2)^2 - 4M_{i\bar{i}}^2 M_{j\bar{j}}^2}]. \quad (3)$$

and

$$\frac{\beta'_{i\bar{j}}}{\beta'_{i\bar{i}}} = \frac{1}{4M_{i\bar{j}}^2} \times [(4M_{i\bar{j}}^2 + M_{i\bar{i}}^2 - M_{j\bar{j}}^2) \pm \sqrt{(4M_{i\bar{j}}^2 - M_{i\bar{i}}^2 - M_{j\bar{j}}^2)^2 - 4M_{i\bar{i}}^2 M_{j\bar{j}}^2}]. \quad (4)$$

The details of this study can be found in Refs. [16, 17, 19–22]. In this study, we compute the mass spectra of the D_s meson, which consists of one strange quark and one charm quark. Hence, using the above obtained relations, the Regge slopes (β') for the D_s meson are extracted as 0.503041 ± 0.00077 GeV^{-2} and 0.560456 ± 0.02323 GeV^{-2} for 0^- and 1^- trajectories respectively. Since, from eq. (1) we can also write,

$$M_{J+1} = \sqrt{M_J^2 + \frac{1}{\beta'}}, \quad (5)$$

Therefore, by utilizing the value of the Regge slope (β'), from the aforementioned equation, we can estimate the masses of the orbitally excited states for $L = 1, 2, 3, 4 \dots$

3. Results and discussion

Table 1: Masses of excited states of the D_s meson in the (J, M^2) plane (in MeV).

States	This work	PDG [1]	[11]	[10]	[7]	[23]
$1^1 S_0$	1968.35 ± 0.07	1968.35 ± 0.07	1979	1969	1969	1970
$1^1 P_1$	2421.22 ± 0.63	2459.5 ± 0.6	2549	2574	2528	2530
$1^1 D_2$	2801.82 ± 0.76		2900	2961	2857	2816
$1^1 F_3$	3136.58 ± 0.83		3186	3266	3123	
$1^3 S_1$	2112.20 ± 0.40	2112.2 ± 0.4	2129	2111	2112	2129
$1^3 P_2$	2499.13 ± 14.80	2569.1 ± 0.8	2592	2571	2575	2566
$1^3 D_3$	2833.71 ± 18.45	2860 ± 7	2917	2971	2882	2834
$1^3 F_4$	3132.76 ± 20.44		3190	3300	3134	

The calculated results are summarized in Table 1. The computed mass spectra is compared with the experimentally observed masses mentioned in PDG as well as the outcomes of several theoretical models. The experimentally observed masses of $1P$ states; $D_{s1}(2460)^\pm$ and $D_{s2}^*(2573)^\pm$ are little bit higher than our predicted masses with a mass difference of 38 MeV and 70 MeV respectively. The estimated $1^3 D_3$ state having mass 2833.71 ± 18.45 MeV is close to the experimentally detected resonance having mass 2860 ± 7 MeV with a mass difference of 27 MeV. This state needs more confirmation and in our present work we predict the J^P value of this resonance as 3^- . Further, we compared our evaluated masses with the predictions of other theoretical approaches and a variety of

predictions can be seen from the different approaches. Our results shows a consistent behavior with the outcomes of Refs. [7, 10, 11, 23] with a mass difference of few MeV. Experimental facilities will definitely benefit from the mass value predictions and the quantum number assignment of the observed states as well as the undiscovered resonances in the present work.

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