Spectroscopy and Decay properties of $s\bar{s}$ mesons using Martin-like confinement potential

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Introduction

In high energy physics, the spectroscopy and decay properties of light quark meson plays a significant role both theoretically and experimentally. Study of strangeonium ($s\bar{s}$) is important because mass of strange quark is lower than the heavy flavour quark but it is higher than up and down quarks. So it forms border line between heavy flavour sector and light flavour sector. $s\bar{s}$ meson are poorly understood compared to quarkonia experimentally also [1, 2]. Only some handful states have been confirmed [1]. The main purpose to study $s\bar{s}$ is that some of the reported exotic states may be the excited or mixed states of strangeonia. The difficulty here is the is the lack of experimental data on masses of pure $s\bar{s}$ excited states. In the present study we have computed the masses of strangeonium states, vector decay constant and leptonic decay widths in a relativistic Dirac frame work. We hope that predictions of the reliable theoretical excited states of $s\bar{s}$ will be useful in resolving the exotic states in the light flavour sector.

Theoretical Methodology

It is known that for the study of mesons in the light flavour sector requires relativistic approach. For the present study we have considered the confinement through a Martin-like potential. The form of the model potential is expressed as [3, 4],

$$V(r) = \frac{1}{2}(1+\gamma_0)(\lambda r^{0.1} + V_0) \quad (1)$$

Where λ is the strength of the confinement part of the potential. V_0 is a constant negative potential depth.

The normalized quark wave functions $\psi(\vec{r})$ satisfies the Dirac equation given by

$$[\gamma^0 E_q - \vec{\gamma}.\vec{P} - m_q - V(r)]\psi_q(\vec{r}) = 0. \quad (2)$$

To get binding energy we have solved the two component (positive and negative energy) Dirac equation. Its solution can be written as [3, 4],

$$\psi^{(+)}_{nlj}(\vec{r}) = N_{nlj}\begin{pmatrix} ig(r)/r \\ (\sigma.\hat{r})f(r)/r \end{pmatrix}\mathcal{Y}_{ljm}(\hat{r}) \quad (3)$$

$$\psi^{(-)}_{nlj}(\vec{r}) = N_{nlj}\begin{pmatrix} i(\sigma.\hat{r})f(r)/r \\ g(r)/r \end{pmatrix}(-1)^{j+m_j-l}\mathcal{Y}_{ljm}(\hat{r}) \quad (4)$$

and N_{nlj} is the overall normalization constant.

TABLE I: S - wave mass spectrum for ($s\bar{s}$) (in MeV).

nL	State	Present	Expermental [1]	[2]
1S	1^3S_1	1018.4	1019.4	1019.4
	1^1S_0	958.9	957	957
2S	2^3S_1	1671.7	1680	1680
	2^1S_0	1637.4	...	∼ 1440
3S	3^3S_1	2003.5	2189	∼ 2050
	3^1S_0	1980.1	...	∼ 1950
4S	4^3S_1	2220.2	...	...
	4^1S_0	2202.4	...	...

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The corresponding energy eigen value is given by[3, 4],

$$\epsilon = (E_q - m_q - V_0)(m_q + E_q)^{\frac{1}{21}}(\frac{2}{\lambda})^{\frac{20}{21}} \quad (5)$$

Mass of particular Quark-Anti quark system can be written as [3, 4],

$$M_{Q\bar{Q}} = E_Q + E_{\bar{Q}} - E_{cm} \quad (6)$$

here, E_{cm} in general can be state dependent which we absorb in our potential parameter V_0. Thus, making V_0 as state dependent.

Mass spectra and decay width of $s\bar{s}$

The computed S - wave and P - wave mass spectra of starangeonium ($s\bar{s}$) are tabulated in Table I and II. In the present work, we have also examined vector decay constant and leptonic decay widths for nS states within the relativistic framework.

Result and discussion

In the relativistic framework, we have studied the mass spectrum of strangeonium states.

TABLE II: P-wave mass spectrum for $(s\bar{s})$(in MeV).

nL	State	Present	Expermental [1]	[2]
1P	1^3P_2	1553.3	1525 ± 5	1525 ± 5
	1^3P_1	1409.0	1426.4 ± 0.9	1426.4 ± 0.9
	1^3P_0	1355.1	...	∼ 1500
	1^1P_1	1321.3	1386 ± 19	1386 ± 19
2P	2^3P_2	1901.8	...	∼2000
	2^3P_1	1833.0	...	∼ 1950
	2^3P_0	1796.2	...	∼2000
	2^1P_1	1759.1	...	∼ 1850
3P	3^3P_2	2136.6	...	...
	3^3P_1	2080.4	...	...
	3^3P_0	2048.4	...	...
	3^1P_1	2023.0	...	...

TABLE III: Vector Decay Constant(F_v in MeV) of the S-wave Strangeonium states.

State	Present	Experimental [1]
1S	0.236	0.237
2S	0.135	...
3S	0.116	...
4S	0.091	...

TABLE IV: Leptonic decay width (in keV) of the S-wave Strangeonium states.

State	Present	Experimental [1]	[5]
1S	1.36	1.37	1.38
2S	0.275	...	...
3S	0.166	...	...
4S	0.009	...	...

To obtain these mass spectra we have solved Dirac equations with a martin plus constant confinement potential. The predicted S-wave masses of strangeonium are in very good agreement with experimental [1] results as given in Table I. In our calculations for P-wave, spin-orbit and tensor interactions are included to remove degeneracy of the states. We have also predicted the 3S, 4S, 2P and 3P states for strangeonium from our model. The decay properties of nS states predicted by the model are also listed in in Table III and IV.

Acknowledgments

We acknowledge the financial support from DST-SERB, India (research Project number: SERB/F/8749/2015-16)

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