

γgg and ggg decay width of S -wave Charmonia

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Introduction

Being a system which can be treated non-relativistically, charmonia happen to be an ideal system to test assumptions of QCD. Unlike the case of light quark hadrons, for charmonia the value of strong running coupling constant (α_s) is sufficiently small ≈ 0.30 also the relative binding energy is small so as to make the perturbative calculations possible. From calculated mass spectra of charmonia[1] by solving Schrödinger equation numerically for Coulomb plus power potential and extracted normalised reduced wave function, we compute γgg and ggg decay width of n^3S_1 states of charmonia.

Mass spectra and Decay widths

We consider the non-relativistic Hamiltonian [2-5].

$$H = M + \frac{P^2}{2m} + V(r) \quad (1)$$

Where, M is the sum of the constituent quarks, m is the reduced mass of the system and $V(r)$ is the interaction potential. The interaction potential is considered to be of the form of Cornell potential,

$$V(r) = -\frac{4}{3} \frac{\alpha_s}{r} + Ar \quad (2)$$

Where, α_s is running coupling constant, $4/3$ is colour factor for meson and A is potential strength and its value is taken as 0.191 GeV^2 . In our computation, the potential parameters

namely potential strength A and charm quark mass by fitting the ground state mass with the experimental mass by numerical solution of Schrödinger equation [6]. The excited mass spectra is computed by employing the spin dependent part of the one gluon exchange potential [7, 8]. The potential parameters and numerical solution of wave function is used to compute the decay width of the charmonium states into three gluon and gluons with photon, with radiative QCD correction[9-11].

$$\Gamma(n^3S_1 \rightarrow 3g) = \frac{10(\pi^2 - 9)\alpha_s^3 |R_{nS}(0)|^2}{81\pi m_c^2} \times \left(1 - \frac{3.7\alpha_s}{\pi}\right) \quad (3)$$

$$\Gamma(n^3S_1 \rightarrow \gamma gg) = \frac{8(\pi^2 - 9)e_Q^2 \alpha_s^2 |R_{nS}(0)|^2}{9\pi m_c^2} \times \left(1 - \frac{6.7\alpha_s}{\pi}\right) \quad (4)$$

Here, e_Q is charge of charm quark, α is the effective strong running coupling constant, $R_{nS}(0)$ is the normalised reduced wave function at origin and m_c is mass of charm quark taken to be 1.321 GeV . The computed γgg and ggg decay widths are compared with the experimental data and other theoretical predictions.

Results and Discussion

We compute the mass spectra of charmonia for the potential Eq. (2) and tabulated in Table I along with the PDG and other theoretical models and it is observed that our results are in good agreement with PDG data. The mass difference between the S wave $c\bar{c}$ meson $1^1S_0 - 1^3S_1$ is 82 MeV and $2^1S_0 - 2^3S_1$ is 63 MeV

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TABLE I: S wave mass spectra of $c\bar{c}$ meson (in GeV)

State	Present	PDG [12]	[13]	[14]
1^1S_0	3.004	2.984 ± 0.005	2.981	2.989
1^3S_1	3.086	3.097 ± 0.006	3.096	3.096
2^1S_0	3.645	3.639 ± 0.012	3.635	3.602
2^3S_1	3.708	3.686 ± 0.025	3.685	3.681
3^1S_0	4.124	–	3.989	4.058
3^3S_1	4.147	4.039 ± 0.043	4.039	4.129
4^1S_0	4.534	–	4.401	4.448
4^3S_1	4.579	4.421 ± 0.004	4.427	4.514
5^1S_0	4.901	–	4.811	4.799
5^3S_1	4.942	–	4.837	4.863
6^1S_0	5.240	–	5.151	5.124
6^3S_1	5.277	–	5.167	5.185

TABLE II: Three-gluon decay widths (in keV)

State	Γ_{ggg}	Expt.[12]	[15]	[16]
J/ψ	292.34	59.55 ± 0.18	52.8 ± 5	442.67
$\psi(2S)$	152.98	31.38 ± 0.85	23 ± 2.6	184.32
$\psi(3S)$	120.10			155.60
$\psi(4S)$	104.68			145.51
$\psi(5S)$	98.58			140.34
$\psi(6S)$	89.03			136.87

while that from the experimental data is 113 MeV and 47 MeV respectively. The calculate mass of 3^3S_1 and 4^3S_1 shows 2.7 % and 3.57 % deviation respectively when compared with the experimental value. It can be observed that value of decay width of ggg is higher than the experimental value, but there is only one theoretical approach with which we can compare our result and it can be seen that our

TABLE III: $n^3S_1 \rightarrow \gamma gg$ decay widths (in keV)

State	$\Gamma_{\gamma gg}$	Expt.[12]	[16]
J/ψ	2.81	8.18 ± 0.25	31.042
$\psi(2S)$	1.47	2.93 ± 0.16	12.925
$\psi(3S)$	1.53		10.911
$\psi(4S)$	1.01		10.204
$\psi(5S)$	0.92		9.841
$\psi(6S)$	0.85		9.598

result is considerably less than that. We also compute the annihilation width using Eq. (3) and (4) without using additional parameters and listed in Tab. II and III. On comparing γgg decay width of J/ψ and $\psi(2S)$ states with the experimental result, we observe the difference is of 5.37 and 1.46 keV respectively.

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