Properties of charmonium in a semi-relativistic formalism

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Introduction

Quarkonium system are of great experimental and theoretical interest because their characteristics can be used to understand the nature of their constituents, i.e., to study both the static and dynamic properties of the heavy quarks. Potential model calculations have been quite successful in describing the hadron spectrum. These phenomenological models are either nonrelativistic or relativistic. The prediction of the mass spectrum in agreement with the experiment does not ensure the validity of a model for describing hadronic systems. In a given model, one must also be able to calculate other observables like the decay constants, leptonic decay widths, radiative decay widths, etc. In the present study, we calculate the decay constants, leptonic decay widths, two-photon and two-gluon decay widths of the S wave charmonium.

Model

The mass spectra of $c\bar{c}$ mesons were obtained by solving a two-body relativistic equation [1] consisting of a vector Coulomb-like potential and a scalar power-law confining potential. The three-dimensional harmonic oscillator wave function is employed as a trial wave function and the masses are obtained by the variational method. The model parameters and the wave function that reproduce the mass spectra of the $c\bar{c}$ mesons are then used to investigate some of their decay properties.

Decay constants are a simple probe of the short distance structure of hadrons and hence a useful observable for testing quark dynamics in this regime. The meson decay constant is given by the Van Royen and Weisskopf formula [2]

$$f^2_{p/v}(nS) = \frac{3}{\pi}\frac{|R_{nS}(0)|^2}{M_{p/v}(nS)}$$

The $^3S_1$ states with $J^{PC} = 1^{--}$ can annihilate into lepton pairs or light hadrons through one photon. The partial widths for $^3S_1$ states to decay to a lepton pair through a virtual photon is given by the Van Royen and Weisskopf relation [2]

$$\Gamma(n^3S_1 \to e^+e^-) = \frac{4\pi e_c^2\alpha^2}{3M(nS)} f_v^2 (1 - 16\ \alpha_s/\pi)$$

The C even states of charmonium can decay into two photons and also into two gluons, and the corrresponding decay widths are sensitive to the behaviour of the $c\bar{c}$ wave function at the origin. The two-photon decay width of the pseudoscalar meson is computed using the formula [3]

$$\Gamma(n^1S_0 \to \gamma\gamma) = \frac{12\alpha^2 e_c^4 |R_{nS}(0)|^2}{M^2_{nS}} \times \left(1 + \frac{\alpha_s}{\pi}(\frac{\pi^2}{3} - \frac{20}{3})\right)$$

TABLE I: Decay Constants (in MeV)

State	Present	Exp.	[4]	[5]
J/ψ	459	416	393	411
$\psi(2S)$	317	304	293	279
$\psi(3S)$	273	187	258	174
$\psi(4S)$	251	161		
$\psi(5S)$	236			
$\eta_c(1S)$	468	335	402	429
$\eta_c(2S)$	320		240	56

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Results and Discussion

In the present work, using the model parameters from a semi-relativistic model, we investigated the decay properties of charmonium states. Decay constants, leptonic decay widths and two-photon decay widths are calculated. The obtained results are given in Tables I, II and III in comparison with the experimental results. The values obtained are in good agreement with the experimental results and with the predictions from other theoretical models.

TABLE II: Leptonic Decay Widths (in KeV)

State	Present	Exp.	[6]
J/ψ	3.76	5.55± 0.14	6.60
$\psi(2S)$	1.51	2.33± 0.07	2.40
$\psi(3S)$	1.02	0.86± 0.07	1.42
$\psi(4S)$	0.81	0.58± 0.07	0.97
$\psi(5S)$	0.67		0.70

TABLE III: Two-photon Decay Widths (in KeV)

State	Present	Exp.	[6]	[4]
$\eta_c(1S)$	6.99	7.2± 0.7	8.5	7.18
$\eta_c(2S)$	2.69	<7.0±3.5	2.4	1.71
$\eta_c(3S)$	1.81		0.88	1.21
$\eta_c(4S)$	1.42			

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