Mass spectrum and decays of charmonium states in non-relativistic quark model

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Introduction

Since several different potentials can predict the hadron spectrum but over estimate the decay rates [1-2], one needs other observables in order to test more precisely the resulting wave functions. Hence, transition between various states and their leptonic decay widths are studied. The leptonic decay widths are a probe of the compactness of the $q\bar{q}$ system and provide important information complementary to the level spacings. For better estimations with reference to the experimental values, various corrections due to radiative processes, higher order QCD contributions are required [3]. In this context, the NRQM formalism is found to provide systematic treatment of the perturbative and non-perturbative components of QCD at the hadronic scale [4]. In heavy meson spectroscopy non relativistic models are found to be more suitable in studying the mass spectra, predicting the higher orbital states and other properties like leptonic and two photon decays. The Hamiltonian employed in our model is given by [5],

$$H = K + V_{CONF}(\vec{r}) + V_{OGEP}(\vec{r})$$

The leptonic decay width of the vector meson is by the Van Royen- Weisskopf formula [6].
For the decays of $^1S_0$, $^3P_0$ and $^3P_2$ states into two photons the expressions are given in ref [7].

Results and discussions

The masses of S, P and D wave charmonium states are given in the table 1. We have calculated the mass of X (3872) taking J^{PC} as 2^{-+} which is far from good in agreement with PDG value. Hence we conclude that the possibility of $J^{PC} = 2^{-+}$ cannot be right. Also positive C parity of X (3872) with decay $X \to \pi^+\pi^- J/\psi$ points to the conclusion that X resonance cannot be a pure $c\bar{c}$ system [8].

Table 1. Masses of charmonium states (in MeV)

Meson	Exl. Mass[9]	Calculated mass
$\eta_c(1S)$	2980.3±1.2	2993.65
$\eta_c(2S)$	3637±4	3867.32
J/ Ψ(1S)	3096.916±0.011	3053.43
Ψ(2S)	3686.09±0.04	3885.28
$h_c(1P)$	3525.93 ± 0.27	3527.80
$\chi_{c0}(1P)$	3414.75±0.31	3405.90
$\chi_{c1}(1P)$	3510.66 ± 0.07	3534.60
$\chi_{c2}(1P)$	3556.2±0.09	3580.40
X(3872)	3872.2±0.8	4063.70
Ψ(4040)	4039 ± 1	4050.80

Table 2 and table 3 respectively give calculated values of two photon decays without and with QCD correction for $\eta_c(1S)$ and $\eta_c(2S)$ in comparison with references [10] and [11].

Table 2. Two photon decay width of η_c(1S) [in keV]

Meson	Ref [11]	Γ	Γ′
$\eta_c(2S)$	4.44± 0.48	4.76	3.74

Table 3. Two photon decay width of $\eta_c(2S)$ [in keV]

Meson	Ref [10]	Γ	Γ'
$\eta_c(1S)$	$7.0^{+1.0}_{-0.9}$	7.89	6.2

We have calculated two photon decay widths for χ_{c0} ($^3P_0$) and χ_{c2} ($^3P_2$) states with and without QCD correction. The calculated values are compared with that of reference[12] in table 4

Table 4. Two photon decay width of $\chi_{c0}(1P)$ and $\chi_{c2}(1P)$ [in keV]

Meson	Ref [12]	Γ	Γ'
$\chi_{c0}(1P)$	5.32	4.15	4.19
$\chi_{c2}(1P)$	0.44	0.94	0.62

The calculated values (with and without QCD correction) of leptonic decay width for J/ψ, $\psi(2S)$ and $\Psi(4040)$ are given in table 5. The leptonic decay width calculated for the $\Psi(4040)$ meson without QCD correction nearly agrees with the PDG value given in table 5.

Table 5. Leptonic decay widths of charmonium states [in keV]

Meson	Exl. Leptonic width [36]	Γ	Γ'
J/ Ψ(1S)	5.55±0.14±0.02	5.48	3.6
Ψ(2S)	2.38 ± 0.04	3.36	2.22
Ψ(4040)	0.86 ± 0.07	0.814	0.54

Conclusions

The phenomenological non-relativistic quark model (NRQM) has been employed to obtain the masses of charmonium states. In the NRQM an exhaustive study of leptonic and two photon decay widths have been calculated. The Hamiltonian used in the investigation has kinetic energy, confinement potential and one-gluon-exchange potential (OGEP). The total energy or the mass of the meson is obtained by calculating the energy eigen values of the Hamiltonian in the harmonic oscillator basis. An overall agreement is obtained with the experimental masses and decay widths.

References

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