Mass spectrum of ground state charmonium states in relativistic quark model

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Introduction

Meson physics and the strong interactions have been intimately connected since pions were first introduced by Yukawa to explain the inter-nucleon force. Since then our knowledge of mesons and strong interactions has undergone several revisions due to continuously increasing huge amount of experimental data. Our present understanding of the strong interactions is that it is described by the QCD which describes the interactions of quarks and gluons. In the language of QCD the short distance behaviour is dominated by one gluon exchange, just as in QED which is dominated by one photon exchange. Since QCD has not been solved exactly so far. the study of hadron spectroscopy is done in terms of the models, which in principle have come from the QCD Lagrangian. Since the exact form of confinement from QCD is not known, phenomenological quark models are built incorporating the salient features of QCD[1-5]

Heavy mesons include charmed, charmed-strange, bottom, bottom-strange, bottom-charmed, charmonium and bottomonium states. The spin of the quark and anti quark can couple to either S=0 (spin singlet) or S=1(spin-triplet) states. The parity of a quark- antiquark state with orbital angular momentum L is $P=(-1)^{L+1}$; the charge conjugation eigen value is $C=(-1)^{L+S}$. States are denoted by $^{2S+1}L_J$ with L=0. Thus for L=0 we have $^1S_0$ or $^3S_1$ states.

In this work we have attempted to study the mass spectra, of the ground state heavy $c\bar{c}$ mesons using relativistic quark model. 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 spanned over a configuration space extending up to the radial quantum number $n_{max}= 4$. In this paper we have considered the S- wave heavy mesons with the quark and anti-quark belonging to heavy flavor sector; the charm.

In bottomonium spectroscopy non relativistic models are found to be more suitable in studying the mass spectra, but in case of charmonium spectroscopy we feel relativistic treatment of the model is still justified since charm quark is lighter compared to the bottom quark.

The model

Here the Hamiltonian is given by,

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

The theoretical overview for V_{CONF} used in this model is given in reference[6]. In non relativistic models the effect of confinement of quarks on mesonic states have been incorporated, but the effect of confinement of gluons on mesonic states has not been taken into account. Since the confinement of colour means the confinement of quarks as well as gluons, the confined dynamics of gluons should play a decisive role in determining the hadron spectrum and in hadron-hadron interaction. The hadronic strong interactions are the residue of the colour dynamic QCD, like atomic interactions in QED. The confinement schemes for quarks and gluons have to be more closely connected to each other in QCD and the confinement of gluons has to be taken into account. There are varieties of confinement models for the gluons [7].

In this relativistic model the effect of the confined gluons on the masses of mesons has been studied using the successful current confined model (CCM) [8]. The confined gluon propagators (CGP) are derived in CCM to obtain the confined one gluon exchange potential (COGEP) [8].

The central part of the COGEP is [8],

$$V_{COGEP}^{cent}(\vec{r}) =$$

$$\frac{\alpha_s N^4}{4}\vec{\lambda}_i \times \vec{\lambda}_j \left[D_0(\vec{r}) + \frac{1}{(E+M)^2}\left[4\pi\delta^3(\vec{r}) - c^4 r^2 D_1(\vec{r})\right]\left[1-2/3\vec{\sigma}_i \times \vec{\sigma}_j\right]\right]$$

Results and discussions

The η_c(1S) is the lightest charmonium. Its mass has been determined through fits to the invariant mass spectrum of η_c(1S) decay products in reactions such as $\gamma\gamma \to \eta_c(1S)$ $B \to \eta_c(1S)K$ using all charged or dominantly charged final states, and in $p\bar{p} \to \eta_c(1S) \to \gamma\gamma$. The existence of η_c(2S) was claimed by Crystal Ball collaboration at a mass of 3594 ± 5 MeV. It was observed later by Belle collaboration in $B \to K(K_S K_\pi)$ and $e^+e^- \to J/\psi + X$ at a significantly higher mass. Study of photon-photon collisions by CLEO and BaBar has confirmed it. The J/ψ, the first charmonium state discovered is the lowest $^3S_1$ $c\bar{c}$ state and can couple directly to virtual photons produced in e^+e^- collisions. The most precise mass determination comes from the KEDR collaboration m(J/ψ) = 3096.917 ± 0.010 ± 0.007 MeV. The $\psi(2S)$ resonance was discovered at SLAC in e^+e^- collisions. The most precise $\psi(2S)$ mass measurement comes from KEDR.

The calculated masses of these S wave charmonium states are given in the following table. We have used the recent experimental values [9] for the comparison of obtained mass values. We note here that the mass value obtained for Ψ(4040) considering it as Ψ(3S) agrees with its experimental mass value. This model can also be employed to calculate leptonic, two photon and radiative decay widths.

Table : Masses of charmonium states (in MeV)

Meson	Exl. Mass[9]	Calculated mass
η_c(1S)	2981.0±1.1	2980.09.
η_c(2S)	3638.9±1.3	3567.32
J/ Ψ(1S)	3096.916±0.011	3062.68
Ψ(2S)	3686.109±0.04	3645.57
Ψ(4040)	4039 ± 1	4058.95

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