Properties of bottomonium in a semi-relativistic model

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Introduction

Bottomonium system has come into news recently with the ATLAS detector at the Large Hadron Collider (LHC) discovering the previously unobserved $\chi_b(3P)$ state [1]. The study of heavy quarkonium systems has played an important role in the development of quantum chromo dynamics (QCD). Heavy quarkonium decays may provide useful information on understanding the nature of inter-quark forces and decay mechanisms. Since the hadron spectrum cannot be obtained directly from QCD, one has to use other methods like potential model calculations lattice gauge theory effective field theory etc., to investigate hadron spectrum and its decays. Phenomenological potential models are still one of the important tools to study the hadron spectrum and its decays. These models are either relativistic or nonrelativistic [2,3]. Using a semi-relativistic potential model, we have investigated the spectra and decays of bottomonium system. The Hamiltonian of our model consists of a relativistic kinetic energy term, a vector Coulomb-like potential and a scalar confining potential. Using this Hamiltonian, we have obtained a spinless wave equation, which is then reduced to the form of a single particle Schrodinger equation. The spin dependent potentials are introduced as a perturbation. The three-dimensional harmonic oscillator wave function is employed as a trial wave function and the mass spectrum is obtained by the variational method. The model parameters and the wave function that reproduce the bottomonium spectrum are then used to investigate some of their decay properties.

Model

For a spinless two particle system the relativistic equation is [4],

$$H\varphi = \sqrt{p1^2 + m1^2} + \sqrt{p1^2 + m1^2}\ \varphi \quad (1)$$

The vector potential (V) and scalar potential (U) are introduced through the transformation, $E \rightarrow E - V$ and $m \rightarrow m + U$ and using spherical polar coordinate system, equation (1) can be reduced to Schrodinger equation with an effective potential V_{eff} with energy E_{eff}. The effective potential we have considered is, $V(r) = -A/r$ and $U(r) = B\ A^{\beta}+V_0$, where A, B and β are parameters. The harmonic oscillator wave function is used as the trial wave function, in which oscillator size parameter is used as the variational parameter. The parameters used in the calculation are listed in table 1. The spin dependent correction used, gives the hyperfine splitting between the vector and pseudo scalar states.

Results and discussion:

Table 2, table 3 and table 4 give the leptonic, two photon and two gluon decay widths of the bottomonium. The leptonic decay widths were calculated using the Van Royen-Weisskopff relation [5]. The obtained decay widths are in reasonably good agreement with the experiment and with other theoretical models. In summary, from our calculations we conclude that the semi-relativistic analysis proposed in the present model gives a reasonably good prediction for the spectra and decay rates of bottomonium in agreement with the experiment.

Table 1 Parameters used in our model

Parameters	Value
A	0.4
B	0.395 GeV
β	0.5
V_0	-0.3125 GeV
m_q	4.7 GeV
αs	0.2

Table 2: Leptonic decay widths in (keV)

State	Γ_{l+l-} (without qcd correc.)	Γ_{l+l-} (with qcd correc.)	Exp.[6]
γ(1S)	1.174	0.768	1.340±0.018
γ(2S)	0.398	0.261	0.612±0.011
γ(3S)	0.265	0.173	0.443±0.008
γ(4S)	0.206	0.135	0.272±0.029
γ(5S)	0.176	0.115	0.31±0.07
γ(6S)	0.153	0.100	0.130±0.030

Table 3: Two photon decay widths in (eV)

State	$\Gamma_{\gamma\gamma}$(without qcd correction)	$\Gamma_{\gamma\gamma}$(with qcd correction)	Ref.[7]
η_b(1S)	396	308	300
η_b(1S)	133	104	140
η_b(1S)	88	69	100
η_b(1S)	69	54	
χ_{b0}(1P)	23	23	33
χ_{b2}(2P)	6	4	7
χ_{b0}(2P)	15	15	34
χ_{b2}(2P)	4	3	8

Table 4: Two gluon decay widths in (MeV)

State	Γ_{gg} (without qcd correc)	Γ_{gg} (with qcd correc)	Ref.[7]
η_b(1S)	5.5	7.1	11.5
η_b(1S)	1.9	2.4	5.2
η_b(1S)	1.2	1.6	3.8
η_b(1S)	1.0	1.2	
χ_{b0}(1P)	0.3	0.5	0.96
χ_{b2}(2P)	0.09	0.08	
χ_{b0}(2P)	0.2	0.3	0.99
χ_{b2}(2P)	0.06	0.05	0.35

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