Bottomonium spectrum and leptonic decays in non-relativistic quark model

K.B.Vijaya Kumar, Antony Prakash Monteiro and Bagyesh
Department of Physics, Mangalore University, Mangalagangothri, Mangalore, 574199, India
E-mail:kbvijayakumar@yahoo.com

Introduction

There is a wealth of experimental data in hadron spectroscopy that has emerged from a number of experimental facilities such as BES, E835, CLEO, BaBar, Belle, CDF, DO, NA60 etc. All these experiments are capable of discovering new hadrons, new production mechanisms, new decays and transitions and in general will be providing high precision data sample with higher confidence level. Hence the study of mass spectroscopy and decay rates of quarkonium becomes significant. From the discovery of charmonium states QCD motivated potential models played an important role in understanding quarkonium spectroscopy. The QCD motivated Coulomb plus linear confining potential with colour magnetic spin dependent interactions have described the bottomonium states as in case of charmonium states. In this work the masses of bottomonium states and leptonic decay widths are calculated using non relativistic quark model (NRQM). The Hamiltonian employed in our model is given by [1],

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

The leptonic decay width of the vector meson is by the Van Royen- Weisskopf formula [2].

Results and discussions

The $\eta_b(1S)$ is the ground state of the bottomonium spectrum, discovered by the BABAR collaboration in the $\Upsilon(3S) \to \eta_b \gamma$ decay channel, by exploiting a sample of (109 ±1) million of $\Upsilon(3S)$. The mass of the $\eta_b(1S)$ was expected to lie around 9.4 GeV, hence the analysis consists of the search for a monochromatic photon of about 900 MeV in the $\Upsilon(3S)$ rest frame, accompanied by a set of charged tracks and electromagnetic clusters consistent with a hadronic $\eta_b(1S)$ decay. The measured $\eta_b(1S)$ mass is (9388.9+3.1 −2.3 ± 2.7) MeV, corresponding to a hyperfine splitting of M($\Upsilon(1S)$)–M($\eta_b(1S)$) = (71.4–2.3 +3.1 ±2.7) MeV. It is in agreement with recent lattice results, but a significant disagreement is found with respect to QCD calculations. This result has been confirmed by a similar analysis performed on the $\Upsilon(2S)$ data sample, looking for $\Upsilon(2S) \to \eta_b \gamma$. In this case, a lower energy photon is present, implying a larger non-peaking background but also a better absolute energy resolution, allowing for a better separation of the signal from the other peaking components. From our model calculations we have arrived at a value 9396.4 MeV given in table 1

The vector bottomonium states were the first hadrons with b quarks discovered. The $\Upsilon(1S)$ mass measurements from CUSB and MD1 have a relative precision of one part in 10^5, but are about 0.5 MeV apart. The $\Upsilon(2S)$ determinations by MD1 and DORIS experiments agree well. There is only one measurement of mass of $\Upsilon(3S)$ by MD1. The mass of $\Upsilon(4S)$ state has been determined in scans by BaBar. The two other states namely $\Upsilon(10860)$ and $\Upsilon(11020)$ often identified as $\Upsilon(5S)$ and $\Upsilon(6S)$ were seen in e^+e^- annihilation. Our model calculations of masses of these states are given in table 1.

The n $^3S_1$ ($J^{PC} = 1^{--}$) states are copiously produced in e^+e^- annihilation and can decay via E1 transitions to the 1 ^3P_J and 2 ^3P_J multiplets. The masses of the χ_b states provide valuable tests of the spin-dependence of the various models. In particular, the splittings of the ^3P_J masses are determined by the spin–orbit and tensor terms which are sensitive to the presence of vector and scalar interactions. Our model calculations of masses of these states are given in table 1.

Recently the CLEO collaboration has observed the first D-wave $b\bar{b}$ state in the cascade

$$\Upsilon(3S) \to \chi_b' \gamma \to {}^3D_J \gamma\gamma \to \chi_b \gamma\gamma\gamma \to \Upsilon(1S)\gamma\gamma\gamma\gamma$$

Due to expected transition probabilities it is believed that the observed state is J = 2, 1^3D_2 state [3]. The calculated mass value of $\psi_2(1D)$ meson is given in table 1.

The quark- antiquark assignments for the vector mesons, as well as the fractional values for the quark charges, may be tested from the values of their leptonic decay widths. The leptonic decay width is proportional to the average value of the squared charge, squared wave-function at the origin and the mass of the vector mesons. Using Van Royen- Weisskopf formula we have computed leptonic decay widths of vector mesons $\Upsilon(1S)$ - $\Upsilon(4S)$ which are listed and are compared with experimental values [4] in table 2.

Conclusions

The phenomenological non-relativistic quark model (NRQM) has been employed to obtain the masses of bottomonium states. In the NRQM an exhaustive study of leptonic 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.

Table 1 Masses of bottomonium states (in MeV)

Meson	Experimental Mass[4]	Calculated mass
η_b	$9388.9^{+3.1}_{-2.3} \pm 0.27$	9396.4
$\Upsilon(1S)$	9460.3±0.26	9469.8
$\Upsilon(2S)$	10023.26±0.31	9994.1
$\Upsilon(3S)$	10355.2±0.5	10402.0
$\Upsilon(4S)$	10579.4±1.2	10782.1
$\Upsilon(5S)$	10865.4±8	10992.6
$\Upsilon(6S)$	11019±8	11154.9
$\chi_{b0}(1P)$	9859.44±0.42±0.31	9896.6
$\chi_{b0}(2P)$	10232.5±0.4±0.5	10435.2
$\chi_{b1}(1P)$	9892.78±0.26±0.31	9903.3
$\chi_{b1}(2P)$	10255.46±0.22±0.5	10436.9
$\chi_{b2}(1P)$	9912.21±0.26±0.31	9906.7
$\chi_{b2}(2P)$	10268.65±0.22±0.5	10437.7
$\psi_2(1D)$	10161±0.6±1.6	10134.9

Table 2 Leptonic decay widths of bottomonium states [in keV]

Meson	Experimental Leptonic Decay width [4]	Calculated Leptonic Decay width
$\Upsilon(1S)$	1.34 ± 0.018	1.28
$\Upsilon(2S)$	0.612± 0.011	0.60
$\Upsilon(3S)$	0.443± 0.008	0.55
$\Upsilon(4S)$	0.272± 0.029	0.52

References

[1] Vijaya Kumar K B, Bhavyashri, Yong-Ling Ma, Antony Prakash Monteiro *Int. J. Mod. Phy.* A **22** 4209 (2009).

[2] Van Royen R and Weisskopf V F *Nuovo Cim.* A **50** 617 (1967).

[3] Godfrey S. and Rosner J. L., Phys. Rev. D **64**, 097501 (2001).

[4] Amsler C et al. (Particle Data Group) *Phys. Lett*. B **667** 1 (2008) and its online update.