Quarkonia in effective field theory

Raghav Chaturvedi[1*] and Ajay Kumar Rai[2†]
[1] *Ministry of Education, Dubai, U.A.E. and*
[2] *Department of Physics, Sardar Vallabhbhai National Institute of Technology, Surat, Gujarat, INDIA.*

As per the standard model(SM), matter is composed of quarks and leptons. Quarks carry colour charges and interact via the gauge bosons (gluons). The up(u), down(d), strange(s), charm(c), top(t) and bottom(b) are the six types of quarks, and their masses increase as one goes from u to t. The up, down and strange are considered as light flavour and charm, bottom and top are considered as heavy flavour. As per quantum chromodynamics quarks and antiquarks form a bound state known as meson. The present work is a study of mesons composed of heavy quarks charm and bottom, these type of mesons are called as quarkonium ($c\bar{c}$ called as charmonium and $b\bar{b}$ called as bottomonium) and B_c meson.

Approximately 25 states in the quarkonium family have been observed experimentally by the PDG[1]. Hence, the theoretical studies of the quarkonium is necessary to understand the quark anti-quark dynamics. Quarkonium are interesting hadrons as they are like hydrogen atom of quantum chromodynamics(QCD). Certain theoretical approaches like lattice QCD , chiral perturbation theory, heavy quark effective field theory, non-relativistic effective field theory, QCD sum rules, NRQCD, dynamical equations based approaches like Schwinger-Dyson and Bethe-Salpeter equations (BSE, relativistic flux tube model, an effective super-symmetric approach, quark models and various potential models have tried to explain the phenomena of quark confinement and dynamics of QCD. We use potential model to study quarkonium, which is a nonrelativistic approach using a suitable interaction potential within the Hamiltonian of the Schrödinger equation. A potential considered takes into account both short range(Coulombic) and long range(confinement) contributions.

The potential to calculate the mass spectra is of the form [2–4]

$$\begin{aligned} V(r) &= -\frac{4\alpha_s}{3}\frac{1}{r} + Ar + \\ & \frac{1}{m}\left(-\frac{9\alpha_c^2}{8r^2} + a\log r + C\right) + \frac{1}{m_c^2}V_{(SD)}(r) \end{aligned} \quad (1)$$

the last term in the equation is relativistic correction from pNRQCD(an effective field theory), α_s is running coupling constant and α_c is effective running coupling constant, r is the quark antiquark separation, a and C are the potential parameters.
The calculated masses using the above potential can be found in Tables [II,I,III]. The calculated masses are consistent with experimental masses.

References

[1] P. A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. 2020, 083C01 (2020).

[2] N. Brambilla *et.al.*, Eur. Phys. J. C 71, 1534 (2011); Eur. Phys. J. C 74, 2981(2014).

[3] Raghav Chaturvedi*et.al.*, J.Phys.G 47, 115003 (2020) 11.

[4] Raghav Chaturvedi*et.al.*, Int.J.Theor.Phys. 59, 3508-3532, (2020) 11.

---

[*] Electronic address: `raghavr.chaturvedi@gmail.com`
[†] Electronic address: `raiajayk@gmail.com`

TABLE I: S state mass spectra of $c\bar{c}$ meson (in GeV)

State	Present	Expt.[1]
1^1S_0	2.989	2.984±0.005
1^3S_1	3.094	3.097±0.006
2^1S_0	3.572	3.639±0.012
2^3S_1	3.649	3.686±0.025
3^1S_0	3.998	–
3^3S_1	4.062	4.039±0.043
4^1S_0	4.372	–
4^3S_1	4.428	4.421±0.004
5^1S_0	4.714	–
5^3S_1	4.763	–

TABLE II: S wave mass spectra of $b\bar{b}$ meson (in GeV)

State	Present	Expt. [1]
1^1S_0	9.399	9.398±0.020
1^3S_1	9.470	9.460±0.003
2^1S_0	9.986	9.999±0.040
2^3S_1	10.033	10.023±0.003
3^1S_0	10.315	–
3^3S_1	10.352	10.355±0.005
4^1S_0	10.583	–
4^3S_1	10.615	10.579±0.012
5^1S_0	10.816	–
5^3S_1	10.845	–

TABLE III: S wave mass spectra of $B_c$meson (in GeV)

State	Present	Expt.[1]
1^1S_0	6.274	6.275
1^3S_1	6.332	–
2^1S_0	6.851	6.842
2^3S_1	6.888	–
3^1S_0	7.275	–
3^3S_1	7.306	–
4^1S_0	7.639	–
4^3S_1	7.666	–
5^1S_0	7.967	–
5^3S_1	7.992	–