Chapter 6

Conclusion and Future Scopes

6.1 Conclusion

In this thesis, we have studied the mass spectra and decay properties of hadrons in the light, heavy and mixed (open) flavor sectors. In chapter 1, we have provided brief review of the recent development reported by experiments as well as the theoretical groups. We have also listed various issues, challenges and attempts made in the understanding the dynamics of heavy as well as open flavor sectors.

Chapter 2 corresponds to the spectroscopy of heavy quarkonia that includes charmonia ($c\bar{c}$), bottomonia ($b\bar{b}$) and B_c ($c\bar{b}$) mesons. We have reported a comprehensive study of heavy quarkonia in the framework of nonrelativistic potential model considering the Cornell potential with least possible number of free model parameters such as confinement strength and quark masses. These parameters are fine tuned to obtain the corresponding spin averaged ground state masses of quarkonia determined from experimental data. Further, we predict the masses of excited states including spin dependent part of confined one gluon exchange potential perturbatively. We have also computed the pseudoscalar and vector decay constants, different annihilation widths such as $\gamma\gamma$, gg, $\ell^+\ell^-$, $\gamma\gamma\gamma$, ggg and γgg of heavy quarkonia using nonrelativistic Van-Royen Weiskopf formulae. The first order radiative corrections in computation of these decays provide satisfactory results for the charmonia while no such correction is needed in case of bottomonia for being purely nonrelativistic system. We compute B_c mass spectra employing the quark masses and mean value of confinement strength of charmonia and bottomonia. We have also computed the weak decays of B_c mesons and the computed life time is also consistent with the

PDG data and other theoretical approaches. It is interesting to note here that despite having a c quark, the nonrelativistic calculation of B_c spectroscopy is in very good agreement with experimental data and other theoretical approaches.

In chapter 3, we have computed the masses and decay properties of doubly heavy baryons. We have reported the masses, magnetic moments and radiative decays of doubly heavy baryons in the extended relativistic harmonic confinement model (ERHM). ERHM uses the nonrelativistic reduction of the Dirac equation to study the masses of doubly heavy baryons. This model treats quark and antiquarks on equal basis. The spin averaged masses of the doubly heavy baryons are computed by solving the Dirac equation for harmonic confinement part of the potential. The expectation value of the Coulomb repulsion term is computed perturbatively using the Harmonic oscillator wave function. The spin dependent part of confined one gluon exchange interaction is computed perturbatively for determining the masses of spin $1/2^+$ and $3/2^+$ baryons. The masses are compared with different theoretical approaches and our results are in good accordance with the relativistic quark model and LQCD results. Our prediction on the mass of Ξ_{cc}^{++} match precisely with the LHCb data. We have also computed the magnetic moments using the spin flavor wave function of the respective baryons and compare with other theoretical approaches. Next, we have computed the radiative decay widths ($3/2^+ \rightarrow 1/2^+$) in terms of transition magnetic moments. While the radiative decays are yet to be identified experimentally and also there are wide range of results available in the literature, our results are consistently found to be within the range predicted by different theoretical approaches. We expect the experimental facilities to provide more results not only for the masses of the doubly heavy baryons but also for their decay properties.

In chapter 4, we have presented the mass and decay properties of exotic four quark states. In the literature, there are different models available that consider these states to be independent tetra quark states, dimeson molecules, hadro-charmonium etc. We have considered the Z_c, Z_b and Z_b' to be the dimeson molecules of $D^+\bar{D}^*$, $B\bar{B}^*$ and $B^*\bar{B}^*$ respectively. We consider the modified Woods-Saxon potential to compute the interaction between these mesons. The bound state masses are obtained by solving the Schrödinger equation numerically. It is observed that the computed masses are found to be sensitive to the variation in radius/size of the molecule for generalized Woods-Saxon potential unlike the standard Woods-Saxon potential. We also compute the strong two body decay widths in the phenomenological Lagrangian mechanism. Our results of masses and decay widths are found to be consistent with the experimental data and other theoretical approaches.

While we have employed the nonrelativistic approach for studying the quarkonium, doubly heavy baryons and exotic states in chapters 2, 3 and 4 respectively, we have studied the weak decays of open flavor mesons in chapter 5. We have investigated the leptonic and semileptonic decays of D and D_s mesons within the framework of covariant confined quark model (CCQM) with in-built infrared confinement. The transition form factors have been calculated in the entire physical range of momentum transfer. We have also provided a brief comparison of the form factors with the other theoretical predictions. The parametrization of the form factors is done using the double pole approximation. These form factors are then used in computations of semileptonic branching fractions. We compared our results of the leptonic and semileptonic branching fractions with the recent BESIII, CLEO, *BABAR* data along with the light cone sum rules results and other theoretical predictions. Our results are in good agreement with the experimental data within 10% except for the channel $D_s \to K^0 \ell^+ \nu_\ell$. Our predictions for ratios of the branching fractions are also in excellent agreement with the experimental data. The ratios of the branching fractions for muon channel to electron channel $\mathcal{R}_{\mu/e} \sim 1$ which is consistent with the standard model prediction suggests no violation of lepton flavor universality. For the rare semileptonic decays $D^+_{(s)} \to D^0 \ell^+ \nu_\ell$, our results match with the theoretical predictions and also satisfies the experimental constraint. Low phase space gives a very small branching fraction that makes it difficult to probe experimentally. Experimentally, only BESIII have reported the upper bound on the branching fractions at 90% confidence level. We expect BESIII and other experiments such as LHC-b, Belle, CLEO and PANDA collaborations to throw more light in search of these transitions.

6.2 Future Scope

In chapter 2, we have computed the spectroscopy of heavy quarkonia using Cornell potential. This work can be further extended incorporating the velocity dependent potentials together with the spin dependent ones at order $1/m^2$. Also the spectra can be computed using the pNRQCD potentials. The relativistic approach can give better estimation for mass spectra and decay properties. Further, the same can also be applied for computing the mass spectra for the heavy baryons as well as for exotic states too.

In chapter 5, we have computed the decay properties of $D_{(s)}$ mesons in covariant confined quark model formalism. This study can further be utilised for the comprehensive review for the semileptonic D and D_s meson decays to probe for the probable search for lepton flavor universality. This method is also applicable to the computation of the semileptonic decays of B and B_s meson decays. The decays involving flavor changing neutral currents (FCNC) are the best tool to probe for the new physics beyond standard model because these decays are highly suppressed according to the Standard Model. The FCNCs are yet to be fully explored in the charm decays and CCQM is a promising tool for these decays. This includes the study of rare $D^+ \to \pi^+ \ \ell^+\ell^-$ decay and at quark level this can be induced by $c \to u\ell^+\ell^-$ for $\ell = e$ and μ transition. The new physics in decays involving FCNC can be introduced by the phenomenology of leptoquark, minimal supersymmetric standard models and other approaches. CCQM is the general formalism which can be applied to multiquark states also. Therefore CCQM can be employed for the studying decay properties of baryons as well as exotic states viz. tetraquark, pentaquark hadrons.