Study of Decay Properties of Heavy Flavor and Exotic Hadrons

Abstract

In this thesis, we study the mass spectra and decay properties of heavy quarkonia, doubly heavy baryons, exotic states and open flavor mesons using different approaches. For heavy quarkonia, we employ Cornell potential and the ground state energy is obtained by solving the Schrödinger equation numerically. Using the potential parameters and numerical solution of wave-function, we study the decay properties of charmonia, bottomonia and B_c mesons. The computation of excited state masses and decay properties are then performed without additional parameters. For doubly heavy baryons, we employ the relativistic harmonic confinement potential and ground state energy is obtained using the non-relativistic reduction of Dirac equation. The exotic states are investigated using the modified Woods-Saxon potential by solving the Schrödinger equation numerically. We also compute the leptonic and semileptonic branching fractions of D and D_s mesons in Covariant Confined Quark Model based on the effective field theory formalism.

Organization of the thesis:

The thesis entitled "Study of Decay Properties of Heavy Flavor and Exotic Hadrons" has been organized in total 6 chapters. A chapter-wise brief description of the work done is as follows.

Chapter 1: Theoretical Developments in Particle Physics

This chapter introduces the field of particle physics and its key aspects. Some major experiments in hadron physics and theoretical approaches are outlined. This chapter provides the motivation and objectives of the present work.

Chapter 2: Heavy Quarkonium Spectroscopy

This chapter 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. We predict the masses of excited states including spin dependent part of confined one gluon exchange potential perturbatively. The potential parameters and numerical solution of wave-function are then used to study various decay properties. It is observed that the nonrelativistic treatment for heavy quarkonium gives very good agreement

with experimental data and other theoretical approaches.

Chapter 3: Decay Properties of Heavy Baryons

In this chapter, we compute the masses of heavy flavour baryons using confinement scheme based on harmonic approximation with Lorentz scalar plus vector character. The residual two body coulomb interaction is included to compute the spin average masses. The spin hyperfine interaction of confined one gluon exchange potential is added to the confinement energy to get the masses of baryons. The mass spectra of baryons are computed using spin-flavour wave function for constituent quarks. The magnetic moments in all systems are then computed without additional parameters. We also compute the radiative transition ($3/2^+ \to 1/2^+$) widths of these states. The computed masses, magnetic moments and decay widths are compared with the experimental data and results of other theoretical models.

Chapter 4: Study of Exotic States as Dimesonic Molecules

This chapter is dedicated to the study of newly observed states that require consideration of physics beyond the Standard Model, the exotic states. These are multiquark or hybrid states other than familiar mesons and baryons. We study the tetra-quark Z states considering them as dimesonic molecules employing modified Woods-Saxon plus Coulomb potential for interaction between the constituent mesons. We compute the bound state masses of the exotic states by solving the Schrödinger equation numerically. We also compute the hadronic two body decay width using the Phenomenological Lagrangian mechanism.

Chapter 5: Weak Decays of Open Flavor Mesons

In this chapter, the leptonic and semileptonic decays of charmed meson ($D_{(s)} \to \ell^+\nu_\ell$ and $D_{(s)} \to (P,V)\ell^+\nu_\ell$) are computed in the Covariant Confined Quark Model (CCQM) formalism with the built-in infrared confinement within the Standard Model framework. Here P and V correspond to pseudoscalar and vector mesons respectively. The CCQM is an effective quantum field approach for the hadronic interaction based on effective Lagrangian of hadrons interacting with the constituent quarks. The required form factors are computed in the entire range of momentum transfer and used to determine semileptonic branching fractions.

Chapter 6: Conclusion and Future Scopes

This chapter is an accomplishment of the work done in the thesis. Along with that, we also discuss the future prospects of research in the area of weak decays using the covariant quark model.

List of Publications

Papers in peer reviewed Journals

1. J. N. Pandya, N. R. Soni, N. Devlani, A. K. Rai, "Decay rates and electromagnetic transitions of heavy quarkonia", Chin. Phys. C **39**, 123101 (2015).

2. N. R. Soni and J. N. Pandya, "Decay $D \to K^{(*)}\ell^+\nu_\ell$ in covariant quark model", Phys. Rev. D **96**, 016017 (2017).

3. N. R. Soni, B. R. Joshi, R. P. Shah, H. R. Chauhan, J. N. Pandya "$Q\bar{Q}(Q \in \{b, c\})$ spectroscopy using Cornell potential", Eur. Phys. J. C **78**, 592 (2018).

4. N. R. Soni, M. A. Ivanov, J, G, Körner, J. N. Pandya, P. Santorelli, C. T. Tran, "Semileptonic $D_{(s)}$-meson decays in the light of recent data", Phys. Rev. D **98**, 114031 (2018).

Papers in Conference Proceedings

1. N. R. Soni and J. N. Pandya, "Masses and radiative leptonic decay properties of B_c meson", DAE Symp. Nucl. Phys. **58**, 674 (2013).

2. N. R. Soni and J. N. Pandya, "Semileptonic and pionic decays of doubly strange baryons", DAE Symp. Nucl. Phys. **60**, 694 (2015).

3. A. N. Gadaria, N. R. Soni, J. N. Pandya, "Masses and magnetic moment of doubly heavy baryons", DAE Symp. Nucl. Phys. **61**, 698 (2016).

4. N. R. Soni, J. N. Pandya, "Masses and radiative decay of Ω_{cc}^+ baryon", DAE Symp. Nucl. Phys. **62**, 770 (2017).

5. N. R. Soni, R. R. Chaturvedi. A. K. Rai, J. N. Pandya, "Mass and Hadronic Decay Widths of Z States as Di-meson Molecule", Springer Proc. Phys. **203**, 729 (2018).

6. A. N. Gadaria, N. R. Soni, Raghav Chaturvedi, A. K. Rai, J. N. Pandya, "Decay Properties of Ξ_{cc}^{++} baryons", DAE symp. on Nucl. Phys. **63**, 912 (2018).