Weak Decays of Heavy Light Hadrons

With the advancement of technologies for particle accelerator physics, large number of experiments are conducted at different experimental facilities viz. Tevatron II at FNAL(Fermi National Accelerator Laboratory); SPEAR (Stanford Positron Electron Accelerator Rings) at SLAC (Stanford Linear Accelerator Center); Belle detector at KEKB; ATLAS, CMS and ALICE at LHC (Large Hadron Collider); CDF and D0 at Fermilab and many more. These experimental facilities provide huge amount of data for decay modes and branching fractions of different hadrons. Mighty observations from these facilities provide enough opportunities to work in the field of theoretical high energy physics. Apart from their masses, different hadronic states are identified by their various decay rates and decay channels. Particle Data Group (PDG) lists collates the hadronic states with their experimentally identified decay channels are reported [1].

All fundamental particles except gluons and photons decays through weak interaction, which involves the exchange or production of $W^{\pm}$ or Z bosons. Weak decays are important because the conservation laws which are valid for strong and electromagnetic interaction are broken by weak processes and providing strong explanation for the make-up of the observable universe. Weak decays also allow the flavor changing current and thus responsible for the fact that ordinary stable matter is made up of only up and down type quarks and electrons. Weak decays play an important role to understanding the dynamics of heavy light hadrons and are also a good test probe for physics beyond the standard model.

To understand the dynamics of the hadronic states, we need to study their decay properties. For example, the semileptonic decays of D and B mesons give the accurate determination of Cabibbo-Kobayashi-Maskawa (CKM) matrix since they involve strong as well as weak interaction. There are a variety of theoretical models available in the literature to study the production and decay properties of these states. The most successful theories are based on the first principle such as lattice quantum chromodynamics (LQCD) [2, 3] and QCD sum rules (QCDSR) [4]. Other attempts are based on QCD, perturbative QCD [5], effective field theory [6], Bethe-Salpeter approach [7, 8], quark models [9, 10].

There are phenomenological models such as nonrelativistic QCD (NRQCD) [11, 12], perturbative nonrelativistic QCD (pNRQCD) [13] and models based on potential such as relativistic potential model [14] and models using non-relativistic reduction of Dirac equation [15, 16, 17] to study these hadronic states. Many of these approaches sometimes precisely explain the masses of hadrons but not the decay properties and vice-versa. A comprehensive review of experimental and theoretical status and challenges in study of hadronic decays are found in the literature [18, 19, 20, 21, 22].

Organization of the thesis:

The thesis entitled "Weak Decays of Heavy Light Hadrons" has been organized in total five chapters. A chapter-wise brief description of the work done is as follows.

Chapter 1: Introduction to Particle Physics

The subject of particle physics and some of its important aspects governing the structure of hadrons, their interactions and decay properties of hadrons within the framework of standard model are introduced in this chapter. Conservation laws for hadrons and their consequences are also discussed in detail. Different theoretical approaches and some key experiments regarding hadron physics are also highlighted. This chapter provides the motivation and objective of the present work.

Chapter 2: Covariant Confined Quark Model (CCQM)

The Covariant Confined Quark Model is an effective quantum field theory approach for hadronic interactions. The effective Lagrangian is constructed considering the fact that constituent quarks also interact with hadron. Compositeness condition is used to determine the coupling strength of the hadrons with constituent quarks. Proper expansion of set of quark loop diagrams are used to generate the matrix elements. Vertex form factors for the hadron-quark vertices are used to renormalize the ultraviolet divergences of the quark loops. The in-built feature of infrared confinement helps us to remove divergences in the quark loop diagrams. Quark confinement is achieved by averaging over some vacuum gluon fields. The required form factors are computed in the entire range of momentum transfer and are used to determine branching fractions.

Chapter 3: Weak decays of hadrons

In this chapter, the leptonic and semileptonic decays of B and B_s meson are computed. Required transition from factors are determined in the entire range of momentum transfer using CCQM within the framework of standard model. Semileptonic decays play crucial role in the extraction of Cabibbo-Kobayashi-Maskawa (CKM) matrix element, which describes CP violation and flavor changing processes in Standard Model. Weak decays play an important role in testing the standard model and physics beyond standard model. Weak decays also shed light into the dynamics of heavy quarks. We have calculated rare $b \to d$ decay using CCQM and the findings have been published [23]. We have also computed the decay properties of the heavy light baryons.

Chapter 4: Study of other observable parameters

In this chapter, we study and compute other important observables like helicity, chirality, Forward-Backward asymmetry and longitudinal polarization using CCQM within the framework of standard model. Forward-Backward asymmetry and longitudinal polarization are very sensitive and good probe for CP violation and lepton flavor violating decays and hence are useful measures to study physics beyond standard model.

Chapter 5: Conclusion and Future Scopes

The results obtained in the work are discussed in detail in the concluding chapter. We have provided a detailed study of the semileptonic decays. Our calculation of the normalized decay distribution as a function of recoil parameters is in very good agreement with the experimental data as well as lattice QCD calculations. Further, our computed normalized decay rates are also in excellent agreement with them within reported uncertainties in all calculations. The ratios of the decay widths are also in very good agreement with the experimental data and other literature. We anticipate more detailed results from the experimental facilities in near future. Finally, the future prospects of research in the area of weak decays of hadrons are also explored in detail.

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List of Publications

Papers in peer reviewed Journals

1. N. R. Soni, Aidos Issadykov, A. N. Gadaria, J. J. Patel, J. N. Pandya, "Rare $b \to d$ decays in covariant confined quark model", Eur. Phys. J. A **58** (2022)3,39

2. N. R. Soni, A. N. Gadaria, J. J. Patel, J. N. Pandya, "Semileptonic Decays of Charmed Mesons to Light Scalar Mesons", Phys. Rev. D **102** (2020)1, 016013 .

Papers in Conference Proceedings

1. N. R. Soni, J. J. Patel, A. N. Gadaria, J. N. Pandya, "Decay properties of heavy quarkonia employing Cornell potential", DAE Symp. Nucl. Phys. **65**(2022), 607-608

2. Aidos Issadykov, N. R. Soni, A. N. Gadaria, J. J. Patel, J. N. Pandya, "$B \to \pi$ decay Form Factor from Covariant Confined Quark Model", PoS PANIC2021(2022) 171

3. N. R. Soni, Aidos Issadykov, A. N. Gadaria, J. J. Patel, J. N. Pandya, "Weak rare decays for $B \to \omega$ transition within covariant confined quark model framework", AIP Conf. Proc. 2377(2021)1, 090006

4. Raghav Chaturvedi, Vikas Patel, N. R. Soni, A. N. Gadaria, J. J. Patel, "Computation of decay constant and digluon decay width of Charmonia", AIP Conf. Proc. 2220(2020)1, 140048

5. A. N. Gadaria, J. J. Patel, N. R. Soni, J. N. Pandya, "Masses and decay properties of Σ_c baryons", DAE Symp. Nucl. Phys. **64**(2019), 635-636

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