Study of strong and weak decay processes of mesons involving heavy flavour quarks

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Introduction

The investigation of the properties of mesons composed of a heavy quark and antiquark ($c\bar{c}, b\bar{b}$) gives very important insight into heavy quark dynamics and to the understanding of the constituent quark masses. The theoretical predictions of the heavy quarkonia $c\bar{c}$ and $b\bar{b}$ mesons have rich spectroscopy with many narrow states of charmonium lying under the threshold of open charm production and of bottomonium lying under the threshold of open beauty production. Many of these states have not confirmed or understood by experiments. However, there have been renewed interest in the spectroscopy of the heavy flavoured hadrons due to number of experimental facilities (CLEO, DELPHI, Belle, BaBar, LHCb etc) which have been continuously providing and expected to provide more accurate and new information about these states at the heavy flavour sector.

According to the notion of asymptotic freedom, the strong interactions become feeble at short distances, so that theoretical analysis can be based on the perturbative application of QCD. The nature of the strong interaction manifests the properties of hadrons and their mutual interactions. The study of heavy flavour and open flavour mesons enable tests of fundamental symmetries, and thereby advances our basic understanding of particle physics. The two-photon and two-gluon annihilation rates of S-wave and P-wave heavy quarkonium are helpful for better understanding the details of quark-antiquark interaction and can function as stringent tests for potential models. The measurement of the time-dependent decay rate of open heavy flavour mesons probes the weak interaction and includes the possibility to observe sizable particle anti-particle asymmetries caused by heavy particles and new forces between them that are not predicted by the Standard Model. The weak interaction is the only process in which a quark can change to another quark, or a lepton to another lepton - the so-called " Quantum Flavour Dynamics (QFD)" where the flavour changing decays take place. In this present context, the thesis is focused upon the study of strong and weak decay processes of mesons involving one or more heavy flavour quark/ antiquark.

Chapter 1 contains a brief introduction to the field of heavy flavour physics, recent trends in experimental and theoretical high energy physics. Here, we also discuss the problems and the recent developments related to the topics of the current work.

Chapter 2 deals with the heavy mesons ($c\bar{c}$ and $b\bar{b}$). Here, we study meson spectra of $c\bar{c}$ and $b\bar{b}$ mesons. We use general quantum mechanical rules applicable to powerlike potentials. We employ Martin-like potential [1–4] of the form $V(r) = \lambda r^{\nu} + V_0$ to get the binding energy of $Q\bar{Q}$ systems, the corresponding square of the probability amplitude and to study the masses of quarkonia states, their leptonic and di-gamma decay widths. The hyperfine, spin orbit and tensor interactions are employed to compute the spin splitting of the nS states and the fine splittings of the P and D states.

Chapter 3 starts with the strong interaction decay properties of heavy mesons. The spectroscopic investigation of the experimentally clean quarkonium states deserves major credit

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in the development of Quantum Chromodynamics (QCD), the theory of the strong interaction. The total widths in these decays have traditionally been described as annihilation into gluons, using the corresponding mechanisms known for positronium annihilation into photons but with α_s vertices and combinatoric color factors. It was the spectrum of particles consisting of the 4th generation of quarks (charm) and later the 5th generation (bottom)that strongly supported the viewpoint that mesons could be understood in a way similar to positronium in the electroweak interactions. The spectroscopic parameters that are fixed from the previous chapter and this analysis based on the predicted masses and leptonic decay widths clearly indicates that such states are mixed state or hybrid states.

In **Chapter 4**, we present the mass spectra of open charm (D, D_s) and beauty (B, B_s) mesons in the framework of the relativistic independent quark model [2–4] using a Martin-like potential for the quark confinement. The predicted excited states are in good agreement with the experimental results as well as with the lattice and other theoretical predictions. The precise experimental measurements of the masses of open charm (D, D_s) meson states and open beauty (B, B_s) meson states have provided a real test for the choice of the hyperfine and the fine structure interactions adopted by various models in the study of open flavoured meson spectroscopy. The quark confining interaction of meson is considered to be produced by the non-perturbative multigluon mechanism and this mechanism is unfeasible to estimate theoretically from first principles of QCD and on the other hand, there exists ample experimental support for the quark structure of hadrons. This is the origin of phenomenological models which are proposed to understand the properties of hadrons and quark dynamics at the hadronic scale. In this context for the present study, we assume that the constituent quarks inside a meson are independently confined by an average potential of the form [2] $V(r) = \frac{1}{2}(1+\gamma_0)(\lambda r^{\nu}+V_0)$.

Chapter 5 contains the weak interaction decay properties of heavy-light mesons (mesons with one heavy and one light quark). Here, the parameters that are fixed from the spectroscopic study and the resulting wave functions and binding energies are employed further to compute the decay constant, electromagnetic transition, leptonic decay widths and hadronic decay widths with no additional parameters. The present results for the decay constants, f_P are in excellent agreement with the reported experimental values. Charged mesons produced from a quark and antiquark can decay to a charged lepton pair when these objects annihilate via a virtual $W^{\pm}$ boson. Though the leptonic decays of open flavor mesons belong to rare decay, they have clear experimental signatures due to the presence of highly energetic leptons in the final state. The Cabibbo favored semileptonic and hadronic decays of the open flavoued mesons and their form factors are computed in this study. The form factors relevant to semileptonic and hadronic decays are related to the Isgur-Wise function $\xi(\omega)$ in heavy flavor symmetry. The present study of the mixing parameters of neutral open flavoured mesons are found to be one of the successful attempt to extract the effective quark-antiquark interaction in the case of heavy-light flavour mesons.

In **Chapter 6**, we present a summary and conclusions drawn from this thesis work and provide some insights in this area for future research work.

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References

[1] Manan Shah, Bhavin Patel and P C Vinodkumar, Phys. Rev. D **86**, 034015 (2012).
[2] Manan Shah, Bhavin Patel and P C Vinodkumar, Phys. Rev. D **90**, 014009 (2014).
[3] Manan Shah, Bhavin Patel and P C Vinodkumar, Proc. of the DAE Symp. on Nucl. Phys. **58**, 626 (2013); **59**, 650 (2014); **59**, 638 (2014).
[4] P C Vinodkumar, Manan Shah and Bhavin Patel, Proc. of Science(PoS) (Hadron 2013) 078 (2013).