CHAPTER 7

SUMMARY AND CONCLUSIONS

In this thesis, we have investigated the two-body weak hadronic decays of heavy flavor mesons. It has been found experimentally that two-body decays dominate the decay spectrum. Theoretical focus has also, so far, been on the s-wave meson (i.e. Pseudoscalar and Vector mesons) emitting decays. However, charm and bottom mesons, being heavy, can also emit p-wave mesons, i.e. axial-vector ($A$), tensor ($T$) and scalar ($S$) mesons. Naively, the p-wave mesons emitting decays of the hadrons are expected to be suppressed kinematically due to the large mass of these meson resonances. However, there now exist reasonable amount of experimental data on branching ratios of p-wave emitting decays of charm and bottom mesons which requires theoretical understanding. In our research work, we have studied such weak decays of bottom mesons ($B^-, \bar{B}^0$ and $\bar{B}_s^0$), which are the bound state of $b$ quark a light anti quark and of a uniquely observed bottom-charm ($B_c$) meson made up of both the heavy quarks.

In chapter 2, we lay down the physical and mathematical preliminaries which have been applied for the study of weak decays of mesons emitting the s-wave mesons. To start with we present the hadron spectroscopy upto the bottom level and classification of the weak decays into leptonic, semileptonic and nonleptonic decays. In general, these weak decays proceed through exchange of virtual $W$-boson between the charged weak ($V$-A)
currents. We have discussed the semileptonic decays of the bottom mesons, which proceed via the so-called spectator quark diagrams. Their decay amplitudes can easily be expressed in terms of decay constants of meson or the form factors appearing in the matrix elements of weak hadronic current between the initial and the final states. This forms the basis for the ‘factorization approach’ later applied to the weak nonleptonic decays. These form factors are usually calculated from the phenomenological approaches. We have used $B \rightarrow P$ form factors based on the BSW quark model framework which match well with the experimental information. In the following chapters, we have extended the factorization approach to study $p$-wave meson emitting decays, i.e. $B \rightarrow PA/PT/PS$ decays.

In chapter 3, we have studied hadronic weak decays of bottom mesons emitting pseudoscalar and an axial-vector mesons. After describing the axial-vector meson spectroscopy of the two kinds, i.e. $A(J^{PC} = 1^{++})$ and $A'(J^{PC} = 1^{--})$, we have obtained the decay amplitudes in terms of appropriate meson decay constants and meson to meson transition form factors for the color-favored and color-suppressed diagrams. We have obtained the $B \rightarrow A/A'$ transition form factors using the ISGW II model which provides a more realistic description. Consequently, we have predicted the branching ratios of $B \rightarrow PA$ decays involving $b \rightarrow c$ and $b \rightarrow u$ transitions in the CKM-favored and CKM-suppressed modes. Experimentally, branching ratios of eleven decays have been measured and upper limits are also available for five other decays. Branching ratios predicted in our model reasonably match well with the available experimental data. We found that the decays involving $b \rightarrow c$ transition can have branching ratios of the order of $10^{-3}$ to $10^{-8}$, whereas the decays occurring through $b \rightarrow u$ transition acquire branching ratios of the order of $10^{-5}$ to $10^{-11}$. We have shown that the predicted branching ratios are comparable to that of the $s$-wave meson emitting weak decays. Specifically, the dominant decay modes
$B^- \rightarrow D^0 D^-$ and $\bar{B}^0 \rightarrow D^+ a_1^-$ have branching ratios $1.6 \times 10^{-2}$ and $1.1 \times 10^{-2}$ respectively. We have also compared our predictions with other theoretical results.

In chapter 4, we have studied hadronic weak decays of bottom mesons emitting pseudoscalar and tensor mesons. Because of the tracelessness of the polarization tensor of spin 2 meson and the auxiliary condition the tensor meson does not materialize from the weak currents. Therefore, either color-favored or color-suppressed diagrams contribute to these decays. We employ ISGW II model to determine the $B \rightarrow T$ transition form factors appearing in the decay matrix element of weak currents involving $b \rightarrow c$ and $b \rightarrow u$ transitions. Consequently, we have obtained the decay amplitudes and predicted the branching ratios of $B \rightarrow PT$ decays in CKM-favored and CKM-suppressed modes. Experimentally, there exist branching ratios of only six decay modes, while the upper limits are available for five other decays. We found that the decays involving $b \rightarrow c$ transition have branching ratios of the order of $10^{-4}$ to $10^{-8}$ and decays involving $b \rightarrow u$ transition have branching ratios of the order of $10^{-5}$ to $10^{-11}$. Dominant decay modes are $B^- \rightarrow D^- D^0$, $B^- \rightarrow \pi^- D^0$, $B^- \rightarrow D^0 a_1^-$, $\bar{B}^0 \rightarrow D^- D^0$, $\bar{B}^0 \rightarrow \pi^- D^0$, $\bar{B}^0 \rightarrow D^+ D^-$, $\bar{B}^0 \rightarrow \pi^- D^{*0}$ and $\bar{B}^0 \rightarrow D^0 K^{*0}$. Here also, we have compared the predicted branching ratios with the experimental measurements and also with other theoretical calculations. We have noticed that the calculated branching ratios $B(B^- \rightarrow \pi^- D^0) = 6.7 \times 10^{-4}$ ($7.8 \pm 1.4 \times 10^{-4}$ Expt) and $B(B^- \rightarrow \pi^- f_2) = 7.1 \times 10^{-6}$ ($8.2 \pm 2.5 \times 10^{-6}$ Expt) are in good agreement with the experimental value, whereas the remaining decays seems to acquire contribution from $W$-annihilation diagram to bridge the gap between theoretical and experimental value and the experimental upper limits honored the predicted branching ratios.

In chapter 5, we have studied hadronic weak decays of bottom mesons emitting pseudoscalar and scalar mesons involving $b \rightarrow c$ and $b \rightarrow u$ transitions. To determine the
form factors appearing in the decay matrix element of weak currents of $B \to S$ transition, we use the ISGW II model. Consequently, we obtain the decay amplitude and calculated the branching ratios in the CKM-favored and CKM-suppressed modes. Though, for these decays both kinds of the spectator diagrams can contribute, usually one of these is suppressed due to the small values of the scalar meson decay constants. Therefore, these decays are not seriously affected by the nature of interference of the color-favored and color-suppressed processes. On experimental side, branching ratios of only three decay modes are measured and upper limit is available for one other decay. The main conclusion is that the dominant decays are $B^- \to \pi^- D_0^0$, $B^- \to D^0 \bar{a}_0$, $B^- \to D_s^- D_0^0$, $B^- \to D^- D_0^0$, $\bar{B}^0 \to D_s^+ D_0^-$, $\bar{B}^0 \to D^- D_s^0$, $\bar{B}^0 \to \pi^- D_0^+$, $\bar{B}^0 \to D^0 \bar{a}_0$, $\bar{B}_s^0 \to \pi^- D_{s0}^+$, $\bar{B}_s^0 \to D^0 K_0^0$, $\bar{B}_s^0 \to D_s^+ D_{s0}^-$ and $\bar{B}_s^0 \to D^- D_{s0}^+$. We hope these decays would be the best candidates from experimental point of view. Here also, we have compared our predicted branching ratios with other theoretical calculations.

In chapter 6, we have studied hadronic weak decays of uniquely observed bottom-charm ($B_c$) meson, which is the only quark-antiquark, bound system composed of the heavy quarks ($b, c$) with different flavors. Investigation of the $B_c$ meson decay rates is therefore of special interest compared to the symmetric heavy quarkonium ($\bar{b}b$, $\bar{c}c$) states. Heavy quarkonium states decay through quark-antiquark annihilation processes, while for $B_c$ meson $W$-annihilation diagram is relatively suppressed in comparison to the $W$-emission from either $b$ quark, or $c$ quark. The decay processes of the $B_c$ meson can thus be broadly divided into two classes: bottom changing and bottom conserving (but charm changing) decay modes. Already, there exists an extensive literature for the semileptonic and nonleptonic decays of $B_c$ emitting $s$-wave mesons, pseudoscalar ($P$) and vector ($V$) mesons. However, relatively less work has been done on its kinematically allowed $p$-wave meson...
emitting weak decays. Therefore, we have extended our work to predict $B_c$ decays emitting axial-vector ($A$), tensor ($T$) or scalar ($S$) mesons in the CKM-favored channels and CKM-suppressed channels. Since, there is no experimental information available on these decay modes, we have compared our predictions with other theoretical results. One naively expects the bottom conserving modes to be kinematically suppressed in comparison to the bottom changing modes. However, we have shown that the branching ratios of the bottom conserving are relatively larger than that of the bottom changing mode due to the large difference in the corresponding values of the CKM matrix elements. Particularly, we have found that $B_c^+ \to \pi^+ B_{s1}^0$, $B_c^+ \to \pi^+ B_{s2}^0$ and $B_c^+ \to \pi^+ B_{s10}^0$ are dominant. These observations would help the experimentalists to identify the $p$-wave meson emitting decays of the heaviest bottom meson.

The continued operation and upgrade of the high energy accelerators and the facilities at various labs all over the world ensure that the knowledge and database of High Energy Physics will continue to expand. We hope that the results obtained in the present thesis would act as guide to these experimental searches and help in deciphering the relative strengths of various competing weak decay mechanisms in the heavy flavor sector.