Chapter 1

INTRODUCTION

In the Glashow-Weinberg-Salam (GWS) theory [1,2,3] of electroweak interactions, the coupling of the neutral gauge bosons γ and Z to quarks of different flavour do not occur at tree-level. However, as a result of quark mixing in the charged weak current, such a flavour-changing neutral current (FCNC) arises at the one-loop level. The same happen to the gluon-quark vertex, for which the results can be easily obtained from the analogous photon vertex. Due to the unitarity property of the mixing matrix, there is a suppression by the Glashow-Illiopoulos-Maiani (GIM) mechanism [4], roughly of the order $\Delta m^2/M_w^2$, where Δm^2 is the largest difference of squared masses of the quarks inside the loop. Thus, the processes whose amplitudes originate from such a suppressed FCNC will be very rare.

The exploration of FCNC had brought to some progresses and improvements in several area of researches related to GWS theory. From the study of rare K- mesons decays and $K^0-\overline{K}^0$ mixing, one may determine the constraints on the mass of the charmed quark [5-8], and on the mixing angle [9] in the Kobayashi-Maskawa (KM) matrix. In more recent years, the similar procedure had been used to determine the constraints for the mass and the mixing angle of the top quark from B-mesons decays. Radiative B-mesons decays, from a $b \to s\gamma$ transition, can be used [10] to put an upper bound on the mass of the top quark, and it has been suggested that a strong QCD enhancement [12,13], in the $B \to K^*\gamma$ decay, will put this achievement within reach of the forthcoming experiment. Exploring FCNC's is also possible in e^+e^- physics, where rare Z boson decays can give a top-mass dependent rate $(e.g., Z \to b\bar{s})$, or even a top production mechanism below the $t\bar{t}$ threshold $(e.g., Z \to t\bar{c})$ [14,15].

FCNC's are also of some important to CP violation. Since its discovery [16] in 1964, CP violation has only been confirmed in processes related to $K^0 - \bar{K}^0$ mixing [17]. The earlier result [18] predicts a strong contribution, from 'penguin diagrams,' to the CP-violating parameter ε'/ε. Later, the B-meson system also offers promising aspect of observing CP violating effect. More recently, it has been suggested [19,20] to look for a CP-violating asymmetry in the flavour-changing Z decays mentioned above.

Still, it is the fact that all these processes are so strongly suppressed that makes the search worthwhile, in the sense that any abnormally high rate would definitely signal some new physics beyond the GWS theory or, at least a heavy fourth generation.

The off-shell flavour-changing vertex $\gamma q_i \bar{q}_j$, where i and j are two different flavour indices, has been calculated exactly by Deshpande, Eilam, and Nazerimonfared [21,22], and for the $g q_i \bar{q}_j$ vertex by Chia [23]. These vertices have found its contributions in the studies of various physical phenomena. The $\bar{d}s\gamma$ and $\bar{d}sg$ vertices, for example, contribute towards the CP violation in the decays $K^{\pm} \to \pi^{\pm}\pi^{0}\gamma$ and $\Lambda \to n\gamma$, the $\Delta I = \frac{1}{2}$ rule [24,25] and CP violation in non-leptonic K decays [18], and moreover, the knowledge of $\bar{d}s\gamma$ vertex is required in the calculation of the neutron dipole moment [26].

The flavour-changing vertex $Zq_i\bar{q}_j$ has attracted considerable attention, first in connection with the rare decays of K-meson [5, 27], and later in relation to the flavour-changing decays of Z boson[9,14,15, 28-31]. The calculations of the vertex, with external quarks on mass-shell, has been computed, in Refs.[5-8], with the approximation of keeping only the leading terms in m^2/M_w^2, where m is the mass of the heaviest internal quark. Later, Ma and Pramudita [32] and Inami and Lim [27] redid the calculation with the approximation of neglecting external quarks masses and four-momentum of virtual Z boson. More recently, it was calculated exactly by Soares and Barroso [33]. In the present study, we present an exact calculation of the flavour-changing quark-Z vertex function, and compared to the previous works, a more general expression for the vertex function is obtained.

Chapter 2 reviews and summarizes the $SU(2)\otimes U(1)$ Weinberg-Salam theory, which also contains a brief discussion of the theory to include three generations of quarks. At the end of the chapter, a list of the Feynman rules in the 't Hooft-Feynman gauge, which is essential for our calculations in the subsequent chapters is presented. Chapter 3 contains the explicit calculation of the unrenormalized flavour-changing quark-Z vertex. In Chapter 4, a new renormalization scheme is introduced in which a renormalization prescription is defined and is applied to obtain the renormalized flavour-changing quark-Z vertex function. This is different from the usual way where the counterterms are generated by employing Ward-Takahashi identity. We consider the case when the external quarks are on mass-shell in Chapter 5, and thereby obtain the expression for the on-shell vertex. In Chapter 6, we investigate the application of the on-shell quark-Z vertex function in several decay processes.