Chapter 4

Summary and conclusion

In this thesis, we have studied the coupling constants and electromagnetic transition form factors of η and η' mesons.

Calculation of η-nucleon and η'-nucleon coupling constants, described in Chapter 2, has been performed using a well-known QCD sum rules approach. Our aim was to make a reliable determination of $g_{\eta NN}$ and $g_{\eta' NN}$. To incorporate $\eta - \eta'$ mixing, quark-flavor basis has been used considering its advantages. Light-cone expansion of a quark propagator has been used in order to study the effect of anomalous glue which forms an important component of Fock space of η and η' mesons. The coupling constants have been calculated at unphysical points and then extrapolated to the physical points by performing a linear extrapolation. We have performed numerical analysis in order to get the error estimates. Errors due to different phenomenological parameters, errors due to finite slope and finite range of Borel mass parameter have been calculated and shown explicitly. We have also checked errors arising due to linear extrapolation. We have estimated $g_A^{(0)}$ by using our results on coupling constants and the Goldberger-Treiman relation. The effect of anomalous glue to these coupling constants have been studied explicitly. Our results on $g_{\eta NN}$ and $g_{\eta' NN}$ have been compared with the results involving other approaches. The main findings of this work are,

- Anomalous glue, which is responsible for the large masses of η, η' mesons as well as for the part of spin of the nucleon, is also found to give a substantial contribution to the coupling constants of these mesons with nucleons. The results state that the gluonic contribution, though small at the physical point, becomes sizable off the physical point and dominant far off the physical point particularly for η'. These results are useful for some processes such as photo-production of η and η' mesons off a nucleon target.

- Though nucleon's interpolating field consists of u and d quark only, we found that the coupling constants are sensitive to OZI-violating contribution and it is sizable, both for η and η' mesons. This is expected as the flavor-singlet channel, where quark-antiquark pair propagates with coupling to gluonic intermediate states, is sensitive to OZI-violating processes. Like gluonic contribution, OZI-violating contributions are also found to grow in magnitude off the physical points compared to their values at the physical points.

- Gluonic contribution in the case of η meson is found sizable even though η is largely an octet. Thus, the glue, through $U(1)$ axial anomaly, also affects η. This has also been seen in the decay $N^*(1535) \to \eta N$.

- The values of $g_{\eta NN}$ and $g_{\eta' NN}$ with error estimates are given in Chapter 2. We have also checked the reliability of linear extrapolation and found that errors due to linear extrapolation are negligible.

Thus, we have performed a new QCD sum rule evaluation of η- and η'-nucleon coupling constants. The subject is important both in nuclear and particle physics theory and experiments going at COSY, ELSA, GrAAL, GSI and Mainz. The contribution of the anomalous glue and the inclusion of η, η' mixing are novel features of this study. This study will also help in understanding the non-perturbative glue dynamics and axial U(1) anomaly which are of great importance for the hadron

physics.

The calculation of twist-six corrections to the electromagnetic transition form factors of η and η' mesons, given in Chapter 3, have been done in the widely used pQCD's collinear factorization approach. In the processes involving high momentum transfer, this approach is very useful to study the TFFs hence the structure of hadrons. The operators are expanded near the light-cone, and the singularity structure is determined by a "twist" of an operator. Basic features of transition form factors have been discussed and few important details of theoretical work done on TFFs of pseudoscalar mesons in pQCD have been given in Chapter 2. The TFFs of η, η' mesons have been studied up to twist-four. Our aim was to extend this calculation up to twist-six, thus to update the present theoretical knowledge about the TFFs of η and η' mesons. Lowest order contributions arising due to finite s-quark mass and meson masses have also been introduced. The twist-six results of TFFs have been superimposed on the results of the same up to twist-four, and then compared with the experimental data in order to show its impact explicitly. The main findings of this work are,

- Twist-six corrections to TFFs start as $\sim 1/Q^4$, as is the case for twist-four corrections, but have a smaller coefficient. The cancellations among different contributing Lorentz structures to the total twist-six result make the overall result smaller in magnitude.

- Gluon condensate along with twist-two DA does not contribute to TFFs. We have also found that the contribution from the meson DA having two valance gluons which is special to η, η' mesons, is negligible. But, gluon DA contributes through quark-gluon mixing and renormalization group evolution.

- For η, twist-six corrections are found to be smaller in magnitude than twist-four contribution. But, for η', these two contributions are found to be of comparable magnitude.

- Light-cone sum rules has also been used for calculation of TFFs in the literature [116]. On the basis of rough estimate, we conclude that the use of light-cone sum rules may modify our result by around $\sim 20\%$ largely due to higher Borel mass and higher continuum threshold.

- h_q, as defined by Eq. (3.52), has been found to introduce considerable uncertainty to the result due to the large uncertainty in its numerical value. We have also discussed how the uncertainty of numerical value of h_q can be minimized.

- The main observation of this whole study is that the twist-six corrections to TFFs of η and η' mesons do not make any significant improvement in the total result. Thus, we anticipate that any further higher twist correction will also impact the total result in a similar way.

The calculation of twist-six corrections to η, η' TFFs has been a challenging task as one has to include the $SU(3)_f$ violating effects, which require calculation of all possible Feynman diagrams retaining terms linearly proportional to the s-quark mass. While the corrections coming from twist-six operators are found to be only at the level of few percent, the analytical expressions given in the thesis contribute to the present-day theoretical knowledge about the TFFs of η, η' mesons. It is an important study also in a sense that it is essential to check the contributions of higher order corrections to expansion schemes, even if just to show that the expansion is under control.

Thus, the studies performed in this thesis provide an important theoretical update in the area of the physics of η and η' mesons. It gives important numerical results for coupling constants and TFFs of these mesons. It also sheds light on basic features associated with these mesons and QCD, the theory of strong interaction. All calculations have been done by using widely used QCD techniques and the reliable results have been given along with the estimates of magnitudes of errors. The calculations of twist-six corrections to the TFFs of these mesons can be further updated

by including few more terms in the expansion of lower-twist DAs, taking non-valance quark(gluon) contribution and taking into account k_T-corrections in the low Q^2 side. The inclusion of contributions coming from the photon distribution amplitudes and soft-overlap configuration can also further modify the theoretical results given in the thesis.

The world of pseudoscalar mesons η and η' is fascinating and worth studying mainly due to dynamics of chiral symmetry breaking, non-perturbative glue dynamics and due to the unusual nature of QCD vacuum. The comprehensive knowledge about the reactions involving these mesons can further enrich our knowledge about the hadronic world which embodies a wide array of hadronic phenomena, ranging from terrestrial nuclear physics to the behavior of matter in the early universe.