SYNOPSIS

To understand the observed properties of nucleons from the underlying theory of strong interaction, quantum chromodynamics (QCD), is a challenging task since the QCD remains intractable at low-energy Among the attempts made in dealing with the strong interaction at low energy scales is the QCD sum rule approach Here the hadronic parameters are determined with a controllable accuracy by circumventing the difficulty of performing direct nonperturbative QCD calculations through a combination of operator product expansion and phenomenological identification of nonperturbative quantities as quark condensate, gluon condensate, etc It is also possible to construct QCD based effective theory which describes the processes of strong interaction at low energies This theory is self consistent in terms of expansion in powers of particle momenta, and masses of Goldstone bosons and the η' mass in the chiral limit In another approach, there are models which are believed to represent various aspects of nonperturbative structure of QCD In one such model, nucleon is considered as a statistical system, and a nucleon state is expanded in terms of quark and gluon Fock states In the present thesis, we have used the above three approaches to study various low-energy properties of a nucleon appropriate for the method concerned

The composition, of nucleons in terms of fundamental quark and gluon degrees of freedom has been modeled variously to account for their observed properties In the first part of this thesis, we work in a statistical model in which a nucleon is taken as an ensemble of quark-gluon Fock states A spin up nucleon state has been expanded in Fock states consisting of three valence quarks and a sea consisting of quarks, antiquarks and gluons, and containing up to five constituents which have definite spin and color quantum numbers. The expansion of a Fock state into spin and color states has been done using the assumption of equal probability for each sub state of such a state We also use the approximation in which a quark in the core is not antisymmetrized with an identical quark in the sea, and have treated quarks and gluons as non-relativistic particles moving in S-wave motion We have not taken into account any contribution of s-quark and other heavy quarks, and have covered only ~ 86% of the total Fock states The remaining Fock states have been assumed to be decomposed in approximately same proportion as the earlier discussed case With these approximations, we have calculated the quark contribution to the spin of the nucleons, the ratio of the magnetic moments of the nucleons, their weak decay constant and the ratio of SU(3) reduced matrix elements for the axial current All of these quantities give the integrated results of the Bjorken variable We have also considered two modifications of the above statistical approach with a view to reduce the contributions of the sea components with higher multiplicities, and done the above calculations for these two cases as well Our results of calculation hold good for a typical hadronic energy scale~$1\,GeV^2$ The use of the Melosh rotation, which takes care of relativistic effect of the quark intrinsic transversal motion inside the nucleon, makes agreement with the data better

Determination of meson-nucleon coupling is of particular interest in the study of nucleonic properties It serves as an useful test of low-energy behaviour of QCD, and is an important parameter in the construction of effective field theories with nucleons and mesons as explicit degrees of freedom In the second part of this thesis, we investigate the isospin splitting in the diagonal pion-nucleon coupling constant δg, by studying the vacuum-to-pion matrix element of the correlation function of interpolating fields of a nucleon in the frame work of conventional QCD sum rule

QCD sum rule has also been used earlier in the literature to investigate the pion-nucleon coupling constant ($g_{\pi NN}$) In the existing calculation, we have included quark mass dependent terms, π^0-η mixing term and electromagnetic correction to the quark-meson vertices In order to reduce the direct dependence of δg on the isospin splitting of quark condensates, the sum rules for the proton and the neutron have been divided with their respective chiral-odd mass sum rules Taking into account the different ranges of values used in the literature for quark condensate, gluon condensate, twist-4-parameter, and continuum threshold, we obtain a range of δg and $g_{\pi NN}$ $\delta g = -(4\ 99 \pm 1.97) \times 10^{-2}$ and $g_{\pi NN} = 11\ 44 \pm 2\ 76$ These results have been compared with the corresponding results found in the literature Contributions to δg for its central value coming from various symmetry breaking parameters (mixing angle, fine structure constant, quark mass difference, nucleon mass difference and the isospin splitting of the quark condensate) have also been calculated and it has been found that they individually add up almost linearly to give final value of δg when these are all taken to be non-zero

We have also calculated the difference of pp- and nn- scattering lengths by using the above found result of δg and $g_{\pi NN}$ in the phenomenological Argonne v_{18} potential disregarding the electromagnetic potential part This gives a range of the values of the difference of scattering lengths, which covers the experimental value

In the third part of our thesis, we investigate nucleon self-energy due to gluonic interaction in an effective theory The one-particle irreducible coupling of the topological charge density (Q) to the nucleon (g_{QNN}) is, in part, related to the amount of the spin carried by polarized gluons in a polarized proton, and is expected to be large The mixing of the gluonic term Q to the flavor singlet would-be-Goldstone boson η_0 generates masses largely to the η' and to some extent to the η OZI violation in the η'-nucleon system is a probe of the role of the gluons in a dynamical chiral symmetry breaking in low-energy QCD We have calculated the nucleonic mass arising due to the above gluonic interaction within the framework of heavy baryon chiral perturbation theory, which includes the η' as well This calculation has been done by restricting to one-loop diagrams of the η and η' with the vertices arising due to gluonic interaction with the nucleon Divergences arising from loop diagrams have been regularized using various types of phenomenological form factors The non-trivial structure of the QCD vacuum has also been taken into account The gluonic contribution to the nucleon self-energy, obtained this way, is over and above the contributions associated with meson exchange models This gives a contribution to the nucleon mass which is (2 5-7 5)% of the nucleon mass and negative as compared to the one-loop pion contribution which is typically (10-20)% of the nucleon mass and negative

In the fourth part of the thesis, we have studied the anomaly-anomaly correlator, using QCD sum rules Using the matrix element of anomaly between vacuum and pseudoscalars π, η, and η', the derivative of the correlator at zero momentum $\chi'(0)$ has been evaluated and found to be $\approx 1\ 82\times10^{-3}\mathrm{GeV}^2$ The singlet axial charge of a nucleon is related to $\chi'(0)$ and hence its evaluation is useful for the discussion of the proton-spin problem Assuming that $\chi'(0)$ has no significant dependence on quark masses, the mass of η' in the chiral limit is found to be ≈723MeV The same calculation also yields for the singlet pseudoscalar decay constant in the chiral limit a value of ≈178MeV

We conclude that nucleon is a many body complex system whose low-energy behaviour is determined mainly by strong interaction Non-perturbative approach to QCD, such as QCD sum rule and the QCD based effective theory, and the models such as a statistical model, have a complementary role in exposing different aspects of nucleonic properties