Chapter-I

GENERAL INTRODUCTION

Traditional low energy nuclear physics considers the atomic nuclei to be composed of nucleons interacting through the exchange of mesons. But in particle physics quarks are the constituents of strongly interacting composite particles called hadrons such as nucleons and pions [1,2]. Quarks interact among themselves through the exchange of gluons [3]. The theory describing this type of interaction is known as Quantum Chromodynamics (QCD) because of its association with a new kind of charge called colour and its resemblance to quantum electrodynamics (QED).

The interface between nuclear and particle physics is now the centre of attention for the physics community. This is because the experimental projects in CERN, Europe, DESY and GSI in Germany, KEK, Japan and Fermilab, CEBAF, BNL in USA are all concentrating in this research region. There have been several major break throughs in the theory and experiments in the last few years. One can apply the techniques of particle
physics to nuclear physics and vice versa and look at high density and temperature systems which are likely to be probed in experiments in near future.

The challenge for today's nuclear physics is to explain or improve the understanding of nuclear properties in terms of interactions between quarks. The motivation for this is clear. There is considerable belief that QCD is the fundamental theory of strong interaction. Thus the force that holds the nucleon together has its origin in the interaction between quarks. From the nuclear physics point of view the construction of QCD-based models is a very important subject as there is an obvious necessity to investigate the phenomenology of nuclear constituents and forces from a more fundamental point of view. Perturbative QCD has been very successful in explaining high energy processes which involve large momentum transfer. These include deep inelastic scattering (DIS) of electrons and muons on nucleon targets [4], radiative corrections, $e^+e^-$ hadronic annihilation (jets) and mesonic decays (e.g. $\pi^0 + 2\gamma$) and many more. However, the so called confining region of QCD dominated by small momentum transfers is relevant to low energy nuclear physics and one can not apply perturbative
approaches to this regime due to the non-Abelian structure and associated infrared divergences. The first possibility to explain this regime is achieved by adopting the lattice gauge formulation of QCD as developed by Wilson [5]. This approach uses Monte Carlo methods and is numerically expensive. Besides breaking translational invariance, the continuum limit, in which one recovers QCD is not uniquely defined. Despite of these difficulties, there has been some important progress made by Creutz and others [6,7]. Creutz's numerical results gives strong support for the coexistence of colour confinement and asymptotic freedom in non-Abelian gauge theories.

Alternatively, for the theories of baryons and mesons some effective Lagrangians have been developed. These are modelled on QCD in such a way that some of the features of the theory are understandable in clear physical terms even qualitatively - a feature absent in lattice calculations.

One of the ways of approximating QCD is to consider the number of colours $N_c$ to be large [8,9]. Though this is only three in the real world the use of $1/N_c$ as expansion parameter
works better than one part in three. Often it predicts results within 10% of experiment. In large $N_c$ philosophy one can consider the nucleon through

(i) a relativistic Hartree Fock problem with a potential which fits meson and
(ii) as a soliton in a meson field as done by Skyrme [10] more than twenty five years back.

Another powerful approach invented by Shifman et al [11] is the QCD sum rules using operator product expansion. We will be mostly concerned with these three techniques.

The presentation of the thesis is as follows. Chapter-II begins with a discussion regarding the existence and properties of quarks which follow from hadron spectroscopy and deep inelastic scattering. It then provides an introduction to QCD with the two most important properties: asymptotic freedom and confinement. A motivation and discussion on large $N_c$ QCD for mesons and baryons is given in chapter-III. In chapter-IV mean field models of nucleon and the delta are established with the two-quark vector Richardson potential along with various
prescriptions for a running quark mass in the Dirac Hartree Fock formalism. Chapter-V contains the description on Skyrmion model of nucleon along with calculation of its breathing mode. Chapter-VI deals with the application of QCD sum rules to hadrons at high temperature and density. Following this chapter and comparing with other works changes of hadron properties in a nuclear medium has been discussed in chapter-VII. Summary and concluding remarks have been outlined in chapter-VIII.