NUCLEONIC PROPERTIES IN STATISTICAL MODEL

BY

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A

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CERTIFICATE

This is to certify that the project report entitled **"Nucleonic Properties in Statistical Model"** Submitted by **Ms. Parveer Kaur** of M.Sc. Physics, Thapar University, Patiala, was carried out under the supervision and guidance of **Dr. Alka Upadhyay**. She has not submitted this material for credit towards any other degree at Thapar University, Patiala or any other university.

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Parveer Kaur

ABSTRACT

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 model approach 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. 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 substate 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 ~ 85% 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. Our values makes better agreement with the data .

GREEK ALPHABETS

Alpha	α	A
Beta	β	B
Gamma	γ	Γ
Delta	δ	Δ
Epsilon	Є	E
Zeta	Ξ	Z
eta	H	H
theta	Θ	Θ
iota	Ί	Ι
Lambda	Λ	Λ
mu	μ	M
Pi	Π	∏
rho	P	Ρ
Sigma	σ	∑
tau	τ	Τ
phi	Φ	Φ
chi	Χ	Χ
psi	φ	Ψ

BARYONS (SPIN $\frac{1}{2}$)

BARYON	QUARK CONTENT	CHARGE	MASS
N$\begin{cases} P \\ N \end{cases}$	uud udd	+1 0	938.280 939.573
λ	uds	0	1115.6
$\sum^{+}$	uus	+1	1189.4
$\sum^{0}$	uds	0	1192.5
$\sum^{-}$	dds	-1	1197.3
Ξ^{0}	uus	0	1314.9
Ξ^{-}	dss	-1	1321.3
λ_c^{+}	udc	+1	2281

BARYON (SPIN $\frac{3}{2}$)

BARYON	QUARK CONTENT	CHARGE	MASS
Δ	uuu, uud, udd, ddd	+2, +1, 0, -1	1232
$\sum^{*}$	uus, uds, dds	+1, 0, -1	1385
Ξ^{*}	uss, dss	0, -1	1533
Ω^{-}	sss	-1	1672

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CHAPTER 1 INTRODUCTION

Dramatic progress has been made in particle physics from last few decades. A series of experimental discoveries has firmly established the existence of sub nuclear world of quarks and leptons. The topics that particle physicists study from one day to the next have changed, as the subject has progressed, but behind this progression the final goal has remained the same—to try to understand how the universe came into being. Particle physics tries to answer questions about the origin of our universe by studying the objects that are found in it and the ways in which they interact. This subject has shown how matter is built and tries to explain where it all came from. On the experimental side, in huge accelerators, often several miles in length, we can speed pieces of atoms, particles such as electrons and protons, or even exotic pieces of antimatter, and smash them into one another. By doing so we are creating in a small region of space an intense concentration of energy, which replicates the nature of the universe as it was within a split second of the original Big Bang. Thus we are learning about our origins.

1.1 HIGH ENERGY PHYSICS

"Particle Physics is a branch of physics that studies the elementary constituents of matter and radiation, and the interactions between them. It is also called High Energy Physics, because many elementary particles do not occur under normal circumstances in nature, but can be created and detected during energetic collisions of other particles." [1]

The experimental study of subatomic particles and their interaction has revealed an unexpected layer of substructure underlying the atomic nucleus that has shed light on the evolution of the universe in the earliest moments following the Big-Bang.

To probe deep within atoms we need a source of very short wavelength. As we cannot make gamma-emitting stars in the laboratory, the technique is to use the basic particles, such as electrons and protons, and speed them in electric fields. The higher the speed, the greater is the energy and momentum and the shorter the associated wavelength. So beams of high-energy particles can resolve things as small as atoms. Thus we can probe inside small a distance as we like; all we have to do is to speed the particles up, give them more and more energy to get to ever smaller wavelengths. To resolve distances on the scale of the atomic nucleus, 10−15 m, requires energies of the order of GeV. This is the energy scale of what we call **high-energy physics** [2].

1.2 FUNDAMENTAL PARTICLES AND INTERACTIONS

In particle physics, an elementary particle or fundamental particle is a particle believed not to have substructure; that is, it is believed not to be made up of smaller particles. If an elementary particle truly has no substructure, then it is one of the basic building blocks of the universe from which all other particles are made. All elementary particles are either bosons or fermions (depending on their spin). The quarks, leptons, and gauge bosons are elementary particles. The spin-statistics theorem identifies a quantum statistics that differentiates fermions from bosons. According to this methodology, particl.es normally associated with matter are fermions. They have half-integer spin and are divided into twelve flavours. Particles associated with fundamental forces are bosons and they have integer spin [3].

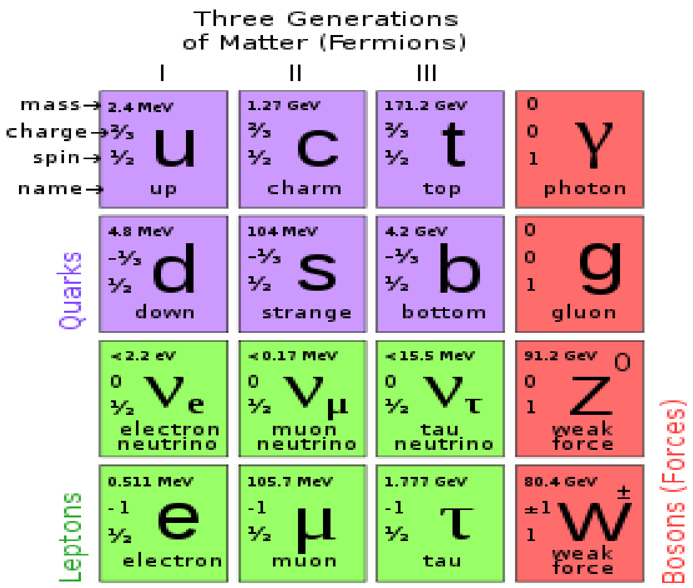

Figure 1.1 Tableaux of all elementary particles

Isolated quarks and antiquarks have never been detected, a fact explained by confinement. Every quark carries one of three color charges of the strong interaction; antiquarks similarly carry anticolor. Color charged particles interact via gluon exchange in the same way that charged particles interact via photon exchange. However, gluons are themselves color charged, resulting in an amplification of the strong force as color charged particles are separated. Unlike the electromagnetic force which diminishes as charged particles separate, color charged particles feel increasing force. However, color charged particles may combine to form color neutral composite particles called hadrons. A quark may pair up with an antiquark: the quark has a color and the antiquark has the corresponding anticolor. The color and anticolor cancel out, forming a color neutral meson. Alternatively, three quarks can exist together, one quark being "red", another "blue", and another "green". These three colored quarks together form a color-neutral baryon. Symmetrically, three antiquarks with the colors "antired", "antiblue" and "antigreen" can form a color-neutral antibaryon.

Fundamental interactions:

The standard model also describes three fundamental interactions known as the strong, electromagnetic and weak interactions. The mediators of the strong force are gluons. The mediator of the electromagnetic force is the photon and the massive $w^{\pm}$ and z^{0} bosons mediate the weak force. Only quarks interact via the strong force and only charged particles interact electromagnetically. All particles interact via the weak force. The fourth fundamental force, gravity is much weaker than the other three mentioned and is not described by the standard model.

Fundamental Force Particles

Force	Particles Experiencing	Force Carrier Particle	Range	Relative Strength*
Gravity acts between objects with mass	all particles with mass	graviton (not yet observed)	infinity	much weaker
Weak Force governs particle decay	quarks and leptons	W^+, W^-, Z^0 (W and Z)	short range	↓
Electromagnetism acts between electrically charged particles	electrically charged	γ (photon)	infinity	↓
Strong Force** binds quarks together	quarks and gluons	g (gluon)	short range	much stronger

Figure 1.2: Fundamental forces

1.3 HADRONS

Hadrons are defined as particles which do interact through the strong force. Hadrons are made of quarks. Thus, hadrons obey all four basic forces of nature. Hadrons can be further subdivided according to their spin:

Hadrons with half-integer spins ($\frac{1}{2},\frac{3}{2},\ldots.$) are fermions and are called Baryons. Baryons are massive particles which are made up of three quarks. [4]

$$B = qqq$$

This class of particles includes the proton and neutron. The lightest baryon is the proton, which is also the only stable hadron in free space. Other baryons are the lambda, sigma, xi and omega particles.

Hadron with integer spins (0, 1, 2...) is bosons and referred to as Mesons. Mesons are intermediate mass particles which are made up of a quark and anti-quark pair i.e.

$$M = q\bar{q}$$

This class of particles includes pions (π^+, π^0). Other mesons are $\pi^-, k^+, k^- and\ \eta$.

However these are not the only hadrons; a great number of them have been discovered and continue to be discovered. The structure of baryons (proton and neutron) and mesons (kaon) are shown in the figure below

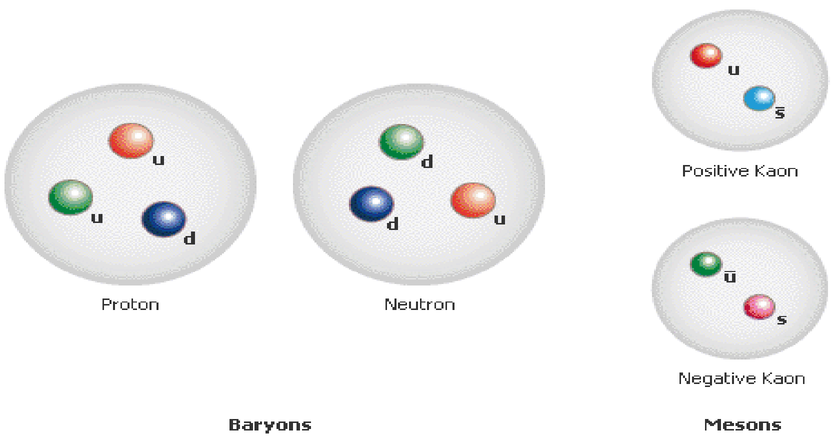

Fig.1.3: Baryons and Mesons contain combinations of quarks and anti-quarks

In 1963 Gell-Mann and Zweig proposed a model that explained the spectrum of strongly interacting particles (i.e. hadrons) in terms of elementary constituents called quarks. Thus **quark model** was developed to account for the regularities observed in the hadron spectrum, with hadrons interpreted as bound states of localized but essentially non-interacting quarks. It provides us a simple picture of internal structure of hadrons and an effective way to describe their dynamics at high energy [5]. Much of the success of the model lies in the circumstance that to a reasonably good approximation; we can regard quarks as free or weakly interacting particles (except for the confining mechanism). This model had great success in predicting new hadronic states, and in explaining the strength of electromagnetic and weak interaction transitions among different hadrons. In particular, it naturally incorporates the most important symmetry relations among hadrons.

Similarly, the **Parton Model** was proposed by Richard Feynman in 1969 as a way to analyse high-energy hadron collisions. In this model, a hadron (for example, a proton) is composed of a number of point-like constituents, termed "partons" [6].The model views the nucleons as made up of point-like constituents and provides a very simple framework for calculating scattering cross sections as well as structure functions for the nucleons. The basic idea of the parton model is that every object with a finite size must have a form factor and therefore experience a dependence on the 4-momentum transfer (Q^2 dependence) from the scattered particle. The experiments at Stanford confirmed the anticipated [7] phenomenon called scale invariance (Bjorken scaling) which proved that scattering of high-energy electrons on the proton was independent of Q^2. This implied that the proton is built up of point-like constituents. Years after the Stanford experiments many experimental results indicated that these partons had the quantum numbers from the quark model and today it has become clear that the partons in Feynman's parton model can be identified as quarks.

1.4 STANDARD MODEL

The Standard Model is the theory of elementary particles and their interactions via the electromagnetic (EM), the weak and the strong forces. Leptons, quarks and bosons (force carriers) are the categories of observed fundamental particles in the SM. They are listed in Figure 1.1. Leptons and quarks are half integer-spin fermions that are divided into three generations. There is a corresponding antiparticle i.e anti-fermion with same mass and spin but opposite-charge-like quantum numbers for each type of lepton and quark. The first generation of fermions contains the particles from which all the ordinary matter in nature is constituted.
We can summarize it this way:

***All of the known matter in the Universe today is made up of quarks and leptons, Held together by fundamental forces which are represented by the exchange of particles known as gauge bosons*.**

Leptons interact via the weak force and, if electrically charged, the EM force, while quarks carry an additional colour charge and hence interact via the strong force as well. The nature of the strong force prevents quarks from being observed in isolation, and therefore quarks always appear in the form of colour-singlet particles called hadrons. In other words, hadrons consist of colour-singlet combinations of quarks. The pion, proton and neutron are examples of hadrons.

The SM is based on three relativistic quantum field theories: Quantum Electrodynamics (QED), the theory of weak interactions and Quantum Chromodynamics (QCD). QED describes the interactions of charged fermions (e, μ, τ and quarks). The theory of weak interactions explains the neutral weak interactions and the charged weak interactions that change the flavour of fermions from one to another. QED and the theory of weak interactions are unified to form the theory of electroweak interactions. QCD describes the strong interactions between quarks.

The interactions between fermions are mediated by integer-spin gauge bosons: the photon (γ) is the mediator of the EM force, the $W^{\pm}$ and Z gauge bosons are the mediators of the weak force, and there are eight gluons (g) that are the mediators of the strong force. The SM is a gauge theory (i.e. symmetric under local phase or gauge transformations), and hence the gauge bosons in principle should be massless. However, the $W^{\pm}$ and Z bosons are massive and acquire mass without violating the gauge invariance through a process called the Higgs Mechanism that introduces a scalar Higgs field. An observable consequence of the Higgs field is a new massive scalar (i.e. spinless) particle called the Higgs boson.

The predictions of the SM have been tested to exceptionally high precision (better than 0.1% in some cases) by a large number of complementary experiments. However, the SM cannot be the complete theory of fundamental physics as it has several universally agreed inadequacies such as: the unverified origin of mass; lack of explanation for why there are exactly three generations; gravity is not included in the theory; and there is no explanation for dark matter.

1.5 GROUPS AND SYMMETRIES

Symmetry considerations dominate modern fundamental physics, both in quantum theory and in relativity. The term “symmetry” is derived from the Greek words sum (meaning ‘with’ or ‘together’) and metron (‘measure’), yielding symmetry. The set of symmetry operations on any system must obey the properties like Closure, Inverse, Identity and Associativity. These define precisely the properties of a *group.* The special unitary groups SU(n) are encountered repeatedly in particle physics theories. It is the group of (n x n) unitary matrices with unit determinant:

$$U^{\dagger}U=UU^{\dagger}=1 \text{ and det. U} = 1$$

SU(2) group determines iso-spin invariance; SU(3)[8] is the ‘eight-fold way’ theory of Gell-mann and Ne’eman.

SU(2) symmetry:

The nuclear forces (strong interactions) are independent of electric charge carried by the nucleons. The strong interacations are invarient under a transformation which changes proton into neutron. More preciesly, the strong interactions has an SU(2) isospin symmetry in which the P and N states form an isospin doublet.

The SU(2) group undertakes the two lightest quark u and d whereas hypercharge is proportional to the net number of strange anti-quarks minus strange quarks or strangeness of a hadron. Iso-spin and hypercharge are both approximately conserved [9]. The group structure of isospin symmetry is very similar to that of usual spin. The isospin generator T_i satisfy the lie algebra of SU(2) as $[T_i, T_j]$ = i$\epsilon_{ijk}T_k$

Where indices ranges from 1 to 3. The proton and neutron form an isospin double $\binom{p}{n}$ means that

$$T_3| \, p> = \frac{1}{2}| \, p>, \qquad T_3| \, n> = -\frac{1}{2}| \, n>$$

The strong interactions do not distinguish proton and neutron means that the strong interactions hamiltonian H_s has the property

$$[T_i, H_s] = 0 \qquad \text{i=1,2,3}$$

The concept of isospin can be extended to other hadrons also. Since different members of isospin multiplets have different electric charges, the electromagnetic interactions clearly do not respect the isospin symmetry. If the symmetry is exact one, then

$$[T_i, H] = 0$$

For the total hamiltonian of the system; all members of the multiplets would be strictly degenrate in mass. Thus the mass difference within an isospin multiplet are good measure of symmetry breaking.

SU(3) Symmetry:

The symmetry group SU(3) is important prominently in elementary particle physics. There are two important and distinct SU(3) symmetries that are relevant for the strong interactions:

First is the SU(3) symmetry for color of the quark and gluon dynamics and second is the SU(3) flavor symmetry of light quarks. Each of these symmetries refers to an underlying three-fold symmetry in strong interaction physics. Mathematically, SU(3) is the group of special unitary 3 x 3 matric.

It is conventional to define the generators of SU(3) in terms of the eight Gell-Mann matrices λ^a

$$T^a = \frac{1}{2}\lambda^a$$

The generators T^a of SU(3) satisfy the commutation relation

$[T^a, T^b] \equiv T^a T^b - T^b T^a = i \sum_{c=1}^{8} f^{abc}\, T^c$

Where f^{abc}, is the structure constant of SU(3) are real numbers.All the higher dimensional representation of SU(3) can be obtained as products of the fundamental(3) and anti-fundamental($\overline{3}$) representations. The product of 3 and $\overline{3}$ representation yield the eight dimensional representations.

The SU(3) color group is the exact symmetry of the standard model, which accounts for the strong interaction of quarks and gluons. The theory of strong interaction is called quantumchromo-dynamics (QCD). Quarks occur in the fundamental three-dimensional representation of SU(3) color. In QCD color charge is conserved in the interactions between quarks, anti-quarks and gluons.

The SU(3) flavor group is an approximate symmetry of QCD resulting from the universality of quark-gluon couplings. All quark flavors with a given color couple to gluons in precisely the same way because gluons are considered flavor blind. The light quarks up, down and strange occur in the fundamental three-dimensional representation of SU(3) flavor. SU(3) flavor symmetry is not an exact symmetry because the masses of the u, d and s quarks are not same and so the quark flavors are distinguishable. Nevertheless, the mass difference of the u, d and s quarks are all small compared to the scale at which the QCD coupling constant becomes large, so neglecting the mass splitting of these three light quarks is a good approximation.

1.6 SYMMETRY BREAKING

Symmetry can be exact, approximate, or broken. The breaking of symmetry does not imply that no symmetry is present, but rather some lower symmetry is present. In group-theory terms, this means that the initial symmetry group is broken to one of its subgroups. Symmetry breaking was first explicitly studied in physics with respect to physical objects and phenomena [10]. However, it is symmetry breaking of the 'laws' that have greater significance in physics. There are two different types of symmetry breakings of the laws: "explicit" and "spontaneous" symmetry breaking.

Explicit symmetry breaking:

Explicit symmetry breaking indicates a situation where the dynamical equations are not manifestly invariant under the symmetry group considered. This means, in the Lagrangian formulation, the Lagrangian of the system contains one or more terms explicitly breaking the symmetry. Such terms can have different origins:

(a) Symmetry-breaking terms may be introduced into the theory by hand on the basis of theoretical/experimental results, as in the case of the quantum field theory of the weak interactions, which is constructed in a way that violates mirror symmetry or parity.

(b) Symmetry-breaking terms may appear in the theory because of quantum-mechanical effects. One reason for the presence of such terms — known as "anomalies" — is that we are moving from the classical to the quantum level. Historically, the first example of an anomaly is that arising from renormalization, so-called chiral anomaly, which is the anomaly violating the chiral symmetry of the strong interaction (see Weinberg, 1996, Chapter 22).

(c) Finally, symmetry-breaking terms may appear because of non-renormalizable effects. Physicists are now viewing current renormalizable field theories as effective field theories, which are low-energy approximations to a deeper theory. The effects of non-renormalizable interactions (due to the heavy particles not included in the theory) are small and can therefore be ignored at the low-energy regime. These “accidental” symmetries, as Weinberg has called them, may then be violated by the non-renormalizable terms arising from higher mass scales and suppressed in the effective Lagrangian (see Weinberg, 1995, pp. 529-531).

Spontaneous symmetry breaking:

Roughly, spontaneous symmetry breaking is said to occur when the symmetry of the Hamiltonian, which governs the dynamics of the physical system, does not lead to a symmetric description of the physical properties of the system.

For spontaneous symmetry breaking to occur, there must be a system in which there are several equally likely outcomes. The system as a whole is therefore symmetric with respect to these outcomes (if we consider any two outcomes, the probability is the same). However, if the system is sampled (i.e. if the system is actually used or interacted with in any way) a specific outcome must occur. Though we know the system as a whole is symmetric, we also know that it is never encountered with this symmetry, only in one specific state. Because one of the outcomes is always found with probability 1, and the others with probability 0, they are no longer symmetric. Hence, the symmetry is said to be spontaneously broken in that theory.

1.7 QUANTUM CHROMODYNAMICS

Quantum Chromo-Dynamics (QCD), the gauge field theory which describes the strong interactions of colored quarks and gluons, is one of the components of the SU(3)×SU(2)×U(1) Standard Model. A quark of specific flavor (such as up(u) quark) comes in 3 colors; gluons come in eight colors; hadrons are color-singlet combinations of quarks, anti-quarks, and gluons. Physicists found that mesons could be classified in groups defined by symmetries under transformations of charge and a new quantum number called strangeness. Figure 4 shows this symmetry for spin 0 mesons. This classification scheme, known as the quark model and developed by Gell-Mann and Nishijima [11], explains the symmetry by postulating three types of quarks, u, d and s, that form the mesons in quark-antiquark pairs and baryons in triplets of quarks or antiquarks.

Quantum chromodynamics (QCD) is the theory of strong interaction with interacting quarks and gluons. It is well tested in the high energy regime where perturbative QCD is applicable. Understanding confinement and hadronic structure in the non-perturbative region of QCD remains a challenge. It describes the interactions of quarks, via their colour quantum numbers. It is an unbroken gauge theory and the gauge bosons are gluons

It is a consistent quantum field theory with a simple and elegant underlying Lagrangian, based entirely on the invariance under a local gauge group, SU(3) colour. Out of this Lagrangian emerges an enormously rich variety of physical phenomena, structures and phases. Exploring and understanding these phenomena is undoubtedly one of the most exciting challenges in modern science.

In QCD, which is to some extent similar to QED, the fundamental interactions are between spin ½ quarks and massless spin 1 gluons. The quarks and gluons carry a new quantum number called colour. Each quark can exist in three different colour states and each gluon in eight colour states. Under an SU(3) group of transformations which mixes up colours, the quarks and gluons are said to transform as a triplet and an octet respectively. No physical particle with the attribute of colour has ever been found, so it is believed that all particles are 'colour neutral'. By this we mean that all physical states must be invariant, or singlet's under color transformations.

The elementary spin - $\frac{1}{2}$ particles of QCD, the quarks, come in six species, or flavors, grouped in a field ψ(x) = (u(x), d(x), s(x), c(x), b(x), t(x))T. Each of the u(x), d(x), etc., is a four-component Dirac spinor field. Quarks experience all three fundamental interactions of the Standard Model: weak, electromagnetic and strong. Their strong interactions involve $N_c = 3$ "color" charges for each quark. These interactions are mediated by the gluons, the gauge bosons of the underlying gauge group of QCD, SU(3) color. The Lagrangian density of QCD in terms of quark and gluon degrees of freedom for interacting quarks with masses mi is given by the equation

$$L_{QCD} = -\frac{1}{4}F_{\mu\nu}^{A}F_{A}^{\mu\nu} + \overline{q_i^a}(i\,D - m_i)_{ab}q_i^b - \frac{1}{2\lambda}\left(A_\mu^A\right)^2 + L_{ghost} \tag{1.1}$$

Here q_i^a quark fields with masses m_i ,A_μ^a is the gluon field and the covariant derivative is given by

$$\left(D_\mu\right)_{ab} = \delta_{ab\mu} + ig_s\left(t^c A_\mu^c\right)_{ab} \tag{1.2}$$

Under the local guage transformations they transform as ($t^a = \frac{\lambda^a}{2}$) are Gell-Mann matrices of SU(3) group.

$$q'_a(x)q_a(x) = \exp\left(it.\theta(x)\right)_{ab}q_b(x)$$

$$= \Omega(x)_{ab}q_b(x).\mathrm{t}.\theta = t^c\theta^c \tag{1.3}$$

$$t.A_\mu t.A'_\mu = \Omega(x)t.A_\mu\Omega^{-1}(x) - \frac{1}{ig}\left(A_\mu\Omega(x)\Omega^{-1}(x)\right) \tag{1.4}$$

$D_\mu q(x) D'_\mu q'(x) = \Omega(x) D_\mu q(x)$ (1.5)

The non-abelian field strength tensor is given by

$F^A_{\mu\nu} = {}_\mu A^A_\nu - {}_\nu A^A_\mu - g_s f^{ABC} A^B_\mu A^C_\nu$ (1.6)

This transforms as

t.$F_{\mu\nu}$t.$F_{\mu\nu}$= Ω(x)t.$F_{\nu\mu}\Omega^{-1}$(x) (1.7)

With the transformations (1.3), (1.5) and (1.7), it is easy to see that L_{QCD} remains invariant under local gauge transformations. The extra term in $F^A_{\mu\nu}$ makes it invariant under non-Abelian gauge transformation. This extra term has profound consequences for the theory: it means that gluons are self-interacting through three- and four-point vertices. This will turn out to give rise to asymptotic freedom at high energies and strong interactions at low energies, among the most fundamental properties of QCD.

Finally, it turns out that in a non-Abelian gauge theory, it is necessary to add one extra term to the Lagrangian density, related to the need for ghost particles. Basically they arise because when a non-Abelian gauge theory is renormalized it is possible for unphysical degrees of freedom to propagate freely. These are cancelled off by introducing into the theory an unphysical set of fields, the ghosts, which are scalars but have Fermi statistics. For practical purposes it is enough to know that there exist Feynman rules for ghosts and that in every diagram with a closed loop of internal gluons, we must add a diagram with them replaced by ghosts. It is worth noting that in physical gauges, as the name suggests, ghost contributions always vanish and they can be ignored.

QCD has similar structure as QED, but with one important difference; the gauge group is non-Abelian SU(3), and gluons are self-interacting. The non-linear three- and four point couplings of the gluon fields A^A_μ with each other are at the origin of the very special phenomena encountered in QCD and strong interaction physics. Hence the theory is asymptotically free (i.e coupling constant decreases at short distances) at high-energy and grows strong at low energies. These interactions are confining and dictates that quarks must be confined within a region of about ~1 Fermi in radius to give a hadron, so one would expect that as two or more nucleons approach each other within a nucleus, quarks and gluons should take over the dynamics and show up in observables. The only stable colour singlet's are quark antiquark pairs, mesons, and three quark states, baryons.

There exist two limiting situations in which QCD is accessible with "controlled" approximations. At momentum scales exceeding several GeV (corresponding to short distances, r<0.1 fm), QCD is a theory of weakly interacting quarks and gluons (perturbative QCD). At low momentum scales considerably smaller than 1GeV (corresponding to long distances, r>1 fm), QCD is characterized by confinement and a non-trivial vacuum (ground state) with strong condensates of quarks and gluons. Confinement is believed to be behind the spontaneous breaking of a symmetry which is exact in the limit of massless quarks: chiral symmetry. Spontaneous chiral symmetry breaking in turn implies the existence of pseudo-scalar Goldstone bosons. For two flavors (N_f = 2) they are identified with the isotriplet of pions (π^+, π^0, π^-). For $N_f = 3$, with inclusion of the strange quark, this is generalized to the pseudoscalar meson octet. Low-energy QCD is thus realized as an Effective Field Theory (EFT) in which these Goldstone bosons are the active, light degrees of freedom.

In QCD, the quarks belong to color triplets of the SU(3) representation where the color charges are defined as red (r), yellow (y) and blue (b). The gauge bosons are the octet of gluons that mediate the color interaction and carry color charge as well. The interactions of the theory include gluon-gluon interactions since they carry color charge as well. The fact that color is not observed directly in nature means there must be exact color symmetry for observable states in QCD.

The confinement of quarks in color singlet states characterizes the theory at small energy (long distance) scales. The inability to derive a quantitative description of confinement stems from the fact that the coupling constant of the strong forces is of order 1 for the binding energy scales within hadrons. If one looks at higher energies however, one sees a running of the coupling constant towards lower values as shown in Fig1.7. This property, known as asymptotic freedom, means quarks will couple “weakly” in high energy interactions and the theory can be treated with a perturbative expansion in powers of the coupling constants [12].

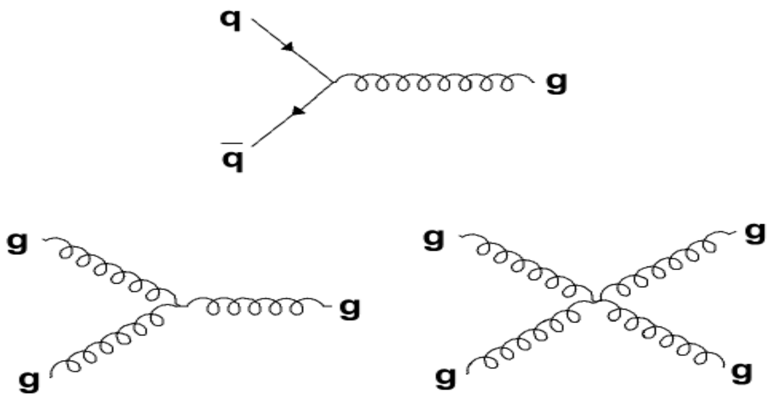

Fig. 1.4: Diagrams of the strong interactions via the gluons of QCD.

ASYMPTOTIC FREEDOM AND CONFINEMENT:

Asymptotic freedom, means that in very high-energy reactions, quarks and gluons interact very weakly. The property of QCD that led directly to its discovery as a candidate theory of the strong interaction is asymptotic freedom, i.e., coupling strength decreases at short distance [7]. This property is due to the presence of gluons which carry color charge and have spin one. It can either be explained as a dielectric or a paramagnetic effect. In first case, one calculates the dielectric properties of the vacuum and ascribes the asymptotic freedom of the theory to the self-interaction of the gluon field. In the later one, asymptotic freedom is explained as a paramagnetic effect due to the spin of the gluons. Confinement has a relatively simple interpretation for heavy quarks and the “string” of (static) gluonic field strength that holds them together, expressed in terms of a static potential. When light quarks are involved, the situation is different. Color singlet quark antiquark pairs prop out of the vacuum as the gluon fields propagate over larger distances. Light quarks are fast movers: they do not act as static sources. In this case the potential picture is not applicable. The common features of the confinement phenomenon can nevertheless be phrased as follows: non-linear gluon dynamics in QCD does not permit the propagation of colored objects over distances of more than a fraction of a Fermi.

Beyond the one-Fermi scale, the only remaining relevant degrees of freedom are color-singlet composites (quasi-particles) of quarks, antiquarks and gluons. Hadron spectra are very well described by the quark model, but quarks have never Hadron spectra are very well described by the quark model, but quarks have never been seen in isolation. Any effort in scattering experiment leads only to the production of the familiar mesons and baryons. Evidently, the forces between quarks are strong. In QFT, when higher order effects in perturbation theory are taken into account, then couplings acquire momentum dependence. An isolated charge in vacuum polarizes the surrounding medium in virtual electron-positron pairs, which, in turn, screen its charge. Hence, when the charge of such a particle is measured by scattering another charged particle on it, the charge depends on the distance between these particles: the smaller the distance, larger is the charge since then the test charge can penetrate inside the charge cloud. In quantum theory, separation is inversely proportional to the momentum transferred.

1.8 PROTON SPIN PROBLEM

The evidence for the existence of quarks inside the proton is given by deep inelastic scattering. The idea is to accelerate electron to very high energies, then allow them to interact with a stationery proton, and investigate what happens. At high energies the wave length associated with the electron are much smaller than the size of the proton. Hence the electrons can probe deep within the the distance that are small compared to the wavelength of the electron.

Deep inelastic scattering may be viewed in two ways: as inelastic scattering of a proton because it has constituents inside, or as elastic scattering from one of the constituents inside. We are able to say that the constituents appear to be point-like and so can be considered to be fundamental particles.

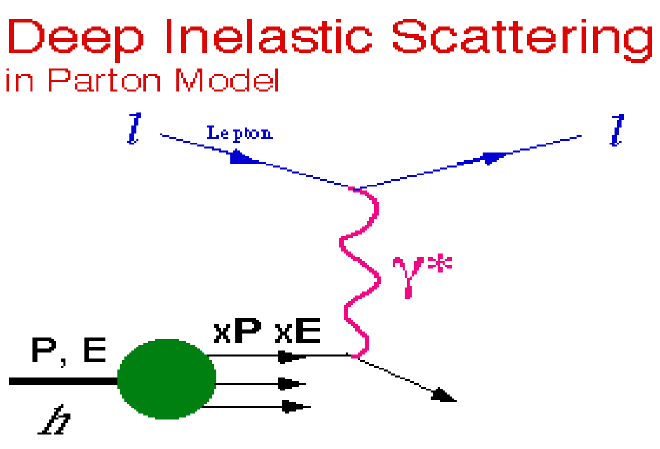

Fig. 1.5: Investigating the structure of proton

The conclusions that only a small fraction of the proton spin is carried by the quarks and that the polarization of sea quarks is negative and substantial lead to some puzzles, for example, where does the proton get its spin from? Why is the total quark spin component small? And why is the sea polarized? The proton spin problem emerges in the sense that experimental results are in contradiction to the naive quark-model's picture. The nonrelativistic SU(6) constituent quark model predicts that $\Delta u = {}^{4}\!/_{3}$, $\Delta d = -{}^{1}\!/_{3}$ and hence$\Delta\Sigma = 1$ but its prediction $g_A = {}^{5}\!/_{3}$ is too large compared to the measured value 1.2573±0.0028 [13]. In the relativistic quark model the proton is no longer a low-lying S-wave state since the quark orbital angular momentum is non-vanishing due to the presence of quark transverse momentum in the lower component of the Dirac spinor. The quark polarizations Δu andΔd will be reduced by the same factor of ${}^{3}\!/_{4}$ to 1 and $-{}^{1}\!/_{4}$, respectively, if g_A^3 is reduced from ${}^{5}\!/_{3}$ to ${}^{5}\!/_{4}$. The reduction of the total quark spin $\boldsymbol{\Delta\Sigma}$ from unity to 0.75 by relativistic effects is shifted to the orbital component of the proton spin so that the spin sum rule now reads [14]

$$\frac{1}{2} = \frac{1}{2}(\Delta u + \Delta d) + L_z^q$$

Hence, it is expected in the relativistic constituent quark model that 3/4 of the proton spin arises from the quarks and the rest of the proton spin is accounted for by the quark orbital angular momentum.

Let Δq be decomposed into valence and sea components, Δq=Δq_v+Δq_s. The experimental fact that $\boldsymbol{\Delta\Sigma} \sim 0.30$, much smaller than the quark-model expectation 0.75, can be understood as a consequence of negative sea polarization [15]:

$$\boldsymbol{\Delta\Sigma} = \boldsymbol{\Delta\Sigma_v} + \boldsymbol{\Delta\Sigma_s} = (\boldsymbol{\Delta u_v} + \boldsymbol{\Delta d_v}) + (\boldsymbol{\Delta u_s} + \boldsymbol{\Delta d_s} + \boldsymbol{\Delta s})$$

Nevertheless, we still encounter several problems. First, in the absence of sea polarization, that $\Delta u_v = 0.92$, $\Delta d_v = -0.34$ and$\Delta\boldsymbol{\Sigma}_v = 0.58$, even if sea polarization vanishes, a substantial part of the proton spin does not arise from the quark spin components. Our question is why the canonical still deviates significantly from the relativistic quark model expectation 0.75 . It turns out that the canonical valence quark polarization is actually a combination of "cloud-quark" and truly valence-quark spin components. Second, in the presence of sea-quark polarization, the spin sum rule must be modified to include all possible contributions to the proton spin:

$$\frac{1}{2} = \frac{1}{2}(\Delta u + \Delta d + \Delta s) + L_z^q + \Delta G + L_Z^G$$

Where, $\Delta G = \int_0^1 \Delta G(x)\, dx \equiv \int_0^1 [G^{\uparrow}(x) - G^{\downarrow}(x)]\, dx$ is the gluon net helicity along the proton spin direction, and $L_Z^{q(G)}$ is the quark (gluon) orbital angular momentum. It is a most great challenge, both experimentally and theoretically, to probe and understand each proton spin contents.

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The vast available data on nucleus indicate that a nucleon is a complicated system of strongly interacting quarks and gluons. Naturally, we require either some non perturbative approach or some models which can capture relevant physics.

Low energy parameters for nucleons can be studied in various models. Like:

1. Chiral Constituent quark model
2. Non-Relativistic quark model
3. Relativistic quark model
4. Statistical model

2.1 CHIRAL CONSTITUENT QUARK MODEL

The constituent quark models [1] have several characteristic properties of QCD in a qualitative manner. 'Constituent quarks' means massive quarks, in contrast to the nearly massless u, d, s quarks of the QCD Lagrangian. These dynamical or constituent masses appear due to the spontaneous chiral symmetry breaking in QCD. As Quantum Chromodynamics (QCD) is the theory of strong interactions. From a theorist's point of view, in strong interactions all dimensionless quantities are taken to be of the order of unity. There are two fundamental facts about strong interactions showing that actually it is not exactly so: there are still certain small parameters hidden. One is that nuclei can be, to a good accuracy is made of weakly bound nucleons — Protons and Neutrons. The second puzzle is that the nucleon itself can be, to a good accuracy, viewed as built of three constituent quarks — in a true 'strong interactions' case it would rather look like a pack of an indefinite number of quarks, antiquarks and gluons. The second puzzle (and probably the first, too) is qualitatively explained by the spontaneous breaking of the (approximate) chiral symmetry of QCD.

It is one of the most successful models in the non-perturbative regime of QCD is the chiral constituent quark model with configuration mixing (χCQMconfig). The basic process in the χCQM is the emission of a GB by a constituent quark which further splits into a $\bar{q}q$ pair as $q_{\pm} \rightarrow GB^{0} + q'_{\mp} \rightarrow (q\bar{q}') + q'$, where $q\bar{q}' + q'$ constitute the "quark sea".

The effective Lagrangian describing interaction between quarks and a nonet of GBs is $\mathcal{L} = g_8 \bar{q} \emptyset_q$,

$$q = \begin{pmatrix} u \\ d \\ s \end{pmatrix}, \qquad \emptyset = \begin{bmatrix} \frac{\pi^0}{\sqrt{2}} + \beta\frac{\eta}{\sqrt{6}} + \zeta\frac{\eta'}{\sqrt{3}} & \pi^+ & \alpha K^+ \\ \pi^- & -\frac{\pi^0}{\sqrt{2}} + \beta\frac{\eta}{\sqrt{6}} + \zeta\frac{\eta'}{\sqrt{3}} & \alpha K^0 \\ \alpha K^- & \alpha \bar{K}^0 & -\beta\frac{2\eta}{\sqrt{6}} + \zeta\frac{\eta'}{\sqrt{3}} \end{bmatrix} \qquad (2.1)$$

where g_8 and ζ are the coupling constants for the singlet and octet GBs.

SU(3) symmetry breaking is introduced by considering $M_s > M_{u,d}$ as well as by considering the masses of GBs to be nondegenerate $(M_{K,\eta} > M_\pi \; and \; M_{\eta'} > M_{K,\eta})$,. The parameter $a = |g_8|^2$ denotes the transition probability of chiral fluctuation of the splitting $u(d) \to d(u) + \pi^{+(-)}$, whereas α^2a, $\beta^2 a \; and \; \zeta^2 a$ respectively denote the probabilities of transitions of $u(d) \to s + k^{-(0)}$, $u(d,s) \to u(d,s) + \eta \; and \; u(d,s) \to u(d,s) + \eta'$.

The spin structure of a baryon can be defined as $\hat{B} \equiv \langle B|\mathcal{N}|B\rangle$, where |B⟩ is the baryon wave function and $\mathcal{N}$ is the number operator, where $\mathcal{N}$=$n_{u_+}u_+ + n_{u_-}u_- + n_{d_+}d_+ + n_{d_-}d_- + n_{s_+}s_+ + n_{s_-}s_-$, the coefficients of $q^\pm$ giving the number of $q^\pm$ quarks.

The wave function for the octet baryons with spin-spin generated configuration mixing can be expressed as

$$|B\rangle \equiv |8, \tfrac{1^+}{2}\rangle = \cos\emptyset \frac{1}{\sqrt{2}}(\chi'\varphi' + \chi''\varphi'')\Psi^s(0^+) + sin\emptyset \frac{1}{2}[(\varphi'\chi'' + \chi'\varphi'')\Psi'(0^+) + (\varphi'\chi' - \varphi''\chi'')\Psi''(0^+)]. \qquad (2.2)$$

For the decuplet baryons, we have

$$|B^* \equiv \Big|10, \tfrac{3^+}{2}\rangle = \varphi^s \chi^s \Psi^s(0^+), \qquad (2.3)$$

Where χ , φ and Ψ are the spin, isospin and spatial wave functions .

2.2 NON-RELATIVISTIC QUARK MODEL

Non-Relativistic quark model [2] is proposed for Baryons, according to which any two quarks are assumed to interact with each other through p-wave forces. Such forces are shown to be capable of producing strong binding in three quark system in a spatially antisymmetric state of angular momentum unity, and making the model compatible with an extension of the [56] representation of SU_6. If the strength of quark-quark force is adjusted to fit some central Baryon mass (m_0), the model predicts a 2-quark bound state at mass$\sim\frac{1}{2}(M+m_0)$ where M is the central mass of the quark.

The "quark" picture of baryon and mesons proposed independently by Gell-Mann and Zweig has proposed a great value for attempts at dynamical formulation of a theory of elementary particles by many authors, using SU_3 symmetry and various relativistic quark models trough appropriate Schrodinger equation. Through such limited approaches it is possible to understand the Gell-Mann–Okubo(GMO) mass formula, the equal interval rule for the Baryon decuplet, the Schwinger mass formula for mesons and the $\frac{3}{2}$ ratio for the nucleon moment. Inspite of these successes, the assumption of non-relativistic quarks would at first sight probably appear unjustified, because of huge binding energies that must be required to offset the effect of the quark rest masses. The most important part is played by the range of $Q-Q$ or $\bar{Q}-Q$ interactions, which should be much shorter than the inverse of, say, a vector meson, to make the huge binding energies compatible with non-relativistic quarks.

One baryon model consists of non-relativistic quarks which interact in pairs. In the limit of SU_3 symmetry, these interactions are taken to be identical. Symmetry breaking is considered only to the extent of unequal masses M_2 and M_1 for the strange and non-strange quarks respectively, where the difference $\Delta M = M_2 - M_1$ is small compared with the central mass $M=\frac{1}{3}(2M_1+M_2)$.

Experimental observations on hadron rest masses, scattering cross sections, and annihilation process are in remarkably a good agreement with a simple additive quark model in which the quarks and antiquarks interact with each other non-relativistically. The potential energy of cluster consisting of n quarks and m antiquarks that is within interaction range of each other in the form

$$V = V_0 \sum_{s=0}^{n} \sum_{t=o}^{m} a(s,t) v_s v_t \tag{2.4}$$

$$V_0 > 0, a(s,t) = a(t,s); a(0,0) = 0 \tag{2.5}$$

Where v_s is the number of ways in which s quarks can be chosen from the n that are present:

$$v_s = n!/(n-s)!\,s! \tag{2.6}$$

For example, with n=3 and m=2, equation (1) and (2) give

$$V = V_0[5a(1,0) + 4a(2,0) + 6a(1,1) + a(3,0) + 9a(2,1) + 2a(3,1) + 3a(2,2) + a(3,2)] \tag{2.7}$$

Several such comments can be made on the foregoing model.

2.3 RELATIVISTIC QUARK MODEL

Despite many efforts solving the bound state problem of QCD a consistent, quantitative description of mesons and baryons is still one of the major challenges in elementary particle physics. If one aims at a comprehensive description of hadronic excitations the most successful approach is doubtless the constituent quark model, where the gluonic degrees of freedom are eliminated in favor of constituent quarks with effective masses and quark interaction potentials. In its non-relativistic version this approach has been most extensively studied by Isgur and Karl[3]. Later on this has been improved, by including relativistic corrections both to the kinetic energy and to the quark potentials. In its non-relativistic version this approach has been most extensively studied by Isgur and Karl. Later on this has been improved, by including relativistic corrections both to the kinetic energy and to the quark potentials. It is the aim of the present contribution to extend a covariant quark model, which we developed for mesons on the basis of the Bethe-Salpeter equation to baryons. The Bethe–Salpeter amplitude for a three-fermion bound state with 4-momentum $\bar{p}$ defined by $\chi\ \bar{p}\ (x_1, x_2, x_3) \equiv \langle 0|T\Psi^1(x_1)\Psi^2(x_2)\Psi^3(x_3)|\bar{p}$ satisfies the homogeneous Bethe Salpeter equation, which after Fourier transformation in momentum space and introduction of the Jacobi-momenta p_ζ, p_η reads

$$\chi\bar{p}(p_\zeta p_\eta) = \quad -iS_i^F(p_1)S_2^F(p_2)S_3^F(p_3)\int\frac{d^4p'_\zeta}{2\pi^4}d^4\frac{p'_\eta}{2\pi^4}K^3(\bar{p}, p_\zeta, p_\eta, p'_\zeta, p'_\eta)\chi\bar{p}(p'_\zeta, p'_\eta) -$$

$$i[S_1^F(p_1)S_2^F(p_2)\int\frac{d^4p'_\zeta}{2\pi^4}K^2(p_1+p_2, p_\zeta, p'_\zeta)\chi\bar{p}(p'_\zeta, p_\eta) + 2\ cycl.perm.] \qquad (2.8)$$

Where S_i^F are the full single quark propagators, $p_i(p_\zeta, p_\eta)$ are single particle 4-momenta depending on the Jacobi-momenta, and K^2 and K^3 are the two-particle and three particle irreducible interaction kernels, respectively.

2.4 STATISTICAL QUARK MODEL

Proton is the simplest system in which the three colors of QCD neutralize into a colorless object, but its internal quark-gluon structure is still not well understood. The complication comes from the presence of sea quarks in the proton[4]. In all global analyses of parton distribution in nucleons before 1990, a symmetric light-quark $(\bar{u}, \bar{d})$ sea was assumed, based on the usual assumption that the sea of quark-antiquark pairs is produced perturbatively from gluon splitting. However, a surprisingly large asymmetry between the $\bar{u}$ and $\bar{d}$ sea quark distributions in the proton has been observed in recent deep inelastic scattering and Drell-Yan experiments.

The origin of the light flavor sea quark asymmetry to reproduce the recent observed $\bar{d}(x) - \bar{u}(x)$ distribution with a simple statistical model, The basic idea is rather simple: while sea quark antiquark pairs are produced flavor blindly by gluon splitting, $\bar{u}$ quarks have larger probability to annihilate than $\bar{d}$ quarks due to the fact that there are more u quarks than d quarks in the proton, which hence causes the asymmetry. Taking proton as an ensemble of quark-gluon Fock states[5] and using the principle of detailed balance for transitions between various Fock states through creation or annihilation of partons, the probabilities $\rho_{i,j,k}$ of finding the quark-gluon Fock states |{uud}{i, j, k}⟩ have been obtained, with i, j, k the number of $\bar{u}u$ pairs, the number of $\bar{d}d$ pairs, the number of gluons, respectively.

Except these models there are models also which talk about various nucleonic properties and there low energy parameters. In the chiral quark model of Manohar and Georgi [6], QCD quarks propagate in the nontrivial QCD vaccum having qq condensates and this leads to the generation of extra mass to the quarks. As a consequence of this spontaneous chiral symmetry breaking, massless pseudoscalar bound qq Goldstone bosons are generated, and this leads to the nontrivial sea structure of the nucleon. In the instanton model [7], the quark-antiquark sea in a nucleon results from a scattering of a valance quark off a nonperturbative vacuum fluctuation of the gluon field, instanton. In the instanton induced interaction described by't Hooft effective lagrangian, the flavor of the produced quark-antiquark is different from the flavor of the initial valance quarks, and there is a specific correlation between the sea quark helicity and the valance quark helicity. In the chiral-quark soliton model [8], the large N_c model of QCD becomes an effective theory of mesons with the baryons appearing as solitons. Quarks are described by single particle wave functions which are solutions of the Dirac equation in the field of the background pions.

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CHAPTER 3 STATISTICAL MODEL AND NUCLEONIC PARAMETERS

3.1 STATISTICAL MODEL APPROACH

The low energy parameters of nucleons can be studied in various models like statistical model, Non-relativistic quark model and relativistic quark model. In nucleon there are protons and neutrons. In many models we consider only the valence part (uud for proton and udd for neutron) which contributes to the spin and mass of the nucleon. But in statistical model we take sea into account, which, in general, contains gluons and virtual quark–antiquark pairs, and is characterized by its total quantum number consistent with the quantum number of nucleons. Since proton and neutron are fermions, they should obey Fermi statistic and hence both valence and sea should combine to give the proton an anti-symmetric wave function.

We write the possible combination of q^3 and sea wave function, which can give a spin-1/2, flavour octet and colour singlet state. One of the goals of hadronic physics is to describe the hadrons in terms of their fundamental quark and gluon degrees of freedom from basic principles. The structure of hadrons has been found to be rather complicated due to the non-perturbative and relativistic nature of the quark and gluon motions inside the hadrons. The sea of hadrons plays a particular role as a source for the complication. There have been many surprising discoveries concerning the structure of the nucleon, and the sea content of the nucleon has been found to be rather more plentiful than expected. For example, it was generally assumed that there should be symmetry between the light flavour *u* and *d* sea quarks inside the proton. However, a surprisingly large asymmetry between the $\bar{u}$ and $\bar{d}$ quark distributions of the proton has been observed from experiments of both deep inelastic scattering and Drell-Yan processes.

Many theoretical attempts have been made to understand the sea flavor asymmetry [1], and it is believed that the mesons inside the nucleon can account for such asymmetry. Recently, there has been a new attempt to understand the sea flavor asymmetry of the proton from a pure statistical consideration in a detailed balance model [2-3]. The idea is rather simple and perspicuous: while the sea quark-antiquark $u\bar{u}$ and $d\bar{d}$ pairs can be produced by gluon splitting with equal probabilities, the reverse processes of the annihilation of the antiquarks with their quark partners into gluons are not flavour symmetric due to the net excess of *u* quarks over *d* quarks. Taking the proton as an ensemble of a complete set of quark gluon Fock states[4], and using the principle of detailed balance that any two nearby Fock states should be balanced with each other, one can obtain the probabilities of finding every Fock state of the proton. Thus one can calculate the quark and gluon content of the nucleon without any parameter from a pure statistical consideration.

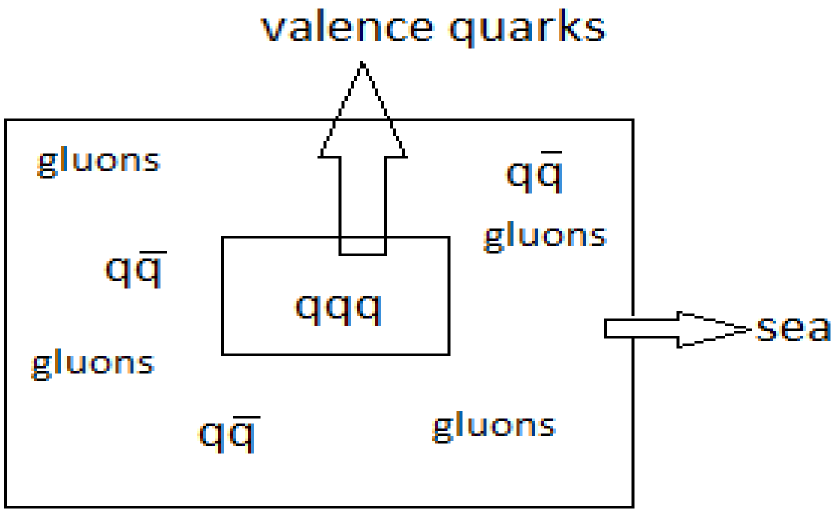
From the above brief review, it is clear that most of the analytical calculations in the literature on the properties of nucleons related to its spin are done in (i) "minimal" quark model which contains at most a gluon or a quark-antiquark pair, in addition to the three valence quarks, or (ii) models where sea acts only as a background specified only by its quantum numbers with no active role in determining the nucleonic properties. In this article, using statistical ideas, we construct such Fock states of a nucleon which have definite color and spin quantum numbers, and definite symmetry property. The resulting total flavor-spin-color wave function of a spin-up nucleon consists of Fock states with three valence quarks and a sea containing up to five constituents (quark-antiquarks and gluons).

Furthermore, if the sea is in an S-wave state relative to the q^3 core, conservation of angular momentum restricts that the spin of the sea can only be 0,1or 2 to give a spin-1/2 proton. The case of the sea with one *qq* pair, where the sea or at least one of the quarks is needed to be in a relative P-wave to meet the positive parity requirement of the proton, will be treated separately. We take the probabilities of finding various quark-gluon Fock states in a proton and assume that the quarks and the gluons can be treated non-relativistically for our problem, and also that, in general, these are in S-wave motion. The effect of the relativistic motion of the constituents will be discussed later. The case of a neutron will be treated in an analogous way using isospin symmetry

3.2 SEA AND ITS STRUCTURE

The fact that nuclei are constructed from nucleons makes their study interesting. Hence the internal structure of the nucleon is of fundamental importance in nuclear and particle physics to both theorist and experimentalist. Various models of nucleons have been suggested to study some aspects of their properties. Our main aim of the thesis is to calculate as many nucleonic parameters as possible in these models and to understand its merits and demerits in the domain of the nucleus.

Composition of nucleon in terms of fundamental quarks and gluons degrees of freedom has been modeled variously to account for its observed properties. Among various models we shall use a statistical model in which a nucleon is assumed to consist of valence quarks surrounded by a sea containing gluons and quark-antiquark pairs, all in nonrelativistic motion in S-wave.



In, treating the proton as an ensemble of quark–gluon Fock states, the proton state has been expanded in a complete set of such states as

$$| \, p >= \sum_{ijk} C_{ijk} | \, uud, i, j, k >, \tag{3.1}$$

where i is the number of $\bar{u}u$ pairs, j is the number of $\bar{d}d$ pairs and k is the number of gluons.

The probability of finding a proton in the Fock state | uud, i,j,k⟩ is

$$\rho_{ijk} = |C_{ijk}|^2 \tag{3.2}$$

where ρ_{ijk}satisfies the normalization condition

$$\sum_{ijk} \rho_{ijk} = 1 \tag{3.3}$$

Then, using the detailed balance principle, and with sub-processes

$$q \Leftrightarrow q\ g,\ g \Leftrightarrow qq \text{ and } g \Leftrightarrow gg \tag{3.4}$$

considered, all ρ_{ijk} have been calculated explicitly.

Therefore, the parton number of quarks and gluons in the proton are

$$u = u_v + \sum_{i,j,k} i\rho_{i,j,k}, \quad (3.5)$$

$$d = d_v + \sum_{i,j,k} j\rho_{i,j,k}, \quad (3.6)$$

$$\bar{u} = \sum_{i,j,k} i\rho_{i,j,k}, \quad (3.7)$$

$$\bar{d} = \sum_{i,j,k} j\rho_{i,j,k}, \quad (3.8)$$

$$g = \sum_{i,j,k} k\rho_{i,j,k} \quad (3.9)$$

Where $u_v = 2$ and $d_v = 1$ are the valence quark numbers of the proton. These partons can be measured by deep inelastic scattering of leptons on the proton target.the quarks and gluons in the Fock state are the "intrinsic" partons of the protons since they are multi connected non-perturbatively to the valence quarks. Such partons are different from the "extrinsic" partons generated from the QCD hard bremsstrahlung and gluon splitting as part of the lepton scattering interaction.

Then a general formula can be derived using formula in Zhang reference,

$$\frac{\rho_{i,j,0}}{\rho_{i-1,j,1}} = \frac{1}{i(i+2)} \quad (3.10)$$

$$\frac{\rho_{i,j,0}}{\rho_{i,j-1,0}} = \frac{1}{j(j+1)} \quad (3.11)$$

Using relation $\rho_{i,j,k} = \rho_{i,j,o}$ got from the formula in these two new formulas, we get

$$\frac{\rho_{i,j,0}}{\rho_{0,j,o}} = \frac{2}{i!(i+2)!} \quad (3.12)$$

$$\frac{\rho_{i,j,0}}{\rho_{i,0,0}} = \frac{1}{j!(j+1)!} \quad (3.13)$$

$$\frac{\rho_{i,j,0}}{\rho_{0,0,0}} = \frac{2}{i!(i+2)!j!(j+1)!} \quad (3.14)$$

Combining formula (3.10) and (3.11), we get

$$\frac{\rho_{i,j,k}}{\rho_{0,0,0}} = \frac{2}{i!(i+2)!(j+1)!k!} \quad (3.15)$$

Thus probabilities of finding the quark-gluon Fock state of the proton, with the sub process g↔gg consideration is calculated in the table below

i	j	$\lvert\{q\},\{i,j,0\}\rangle$	$\rho_{i,j,0}$	$\rho_{i,j,1}$	$\rho_{i,j,2}$
0	0	$\lvert uud\rangle$	0.148793	0.148793	0.081887
1	0	$\lvert uud\bar{u}u\rangle$	0.052960	0.054978	0.030419
0	1	$\lvert uud\bar{d}d\rangle$	0.080334	0.082708	0.045441
1	1	$\lvert uud\bar{u}u\bar{d}d\rangle$	0.029306	0.030569	0.016763
0	2	$\lvert uud\bar{d}d\bar{d}d\rangle$	0.014570	0.015242	0.008381
2	0	$\lvert uud\bar{u}u\bar{u}u\rangle$	0.007231	0.007642	0.004240
1	2	$\lvert uud\bar{u}u\bar{d}d\bar{d}d\rangle$	0.005355	0.005620	0.003073
2	1	$\lvert uud\bar{u}u\bar{u}u\bar{d}d\rangle$	0.004011	0.004223	0.002315

Using the principle of detailed balance, the probabilities of finding the proton in every Fock state are obtained without any parameter. A new origin of the light flavor sea quark asymmetry, i.e., $\bar{u} \neq \bar{d}$, is given as a pure statistical effect.

The $\bar{q}q$ pairs and gluons, which are multiconnected nonperturbatively to the valence quarks, will collectively be referred to as the sea model.

3.3 BARYON WAVEFUNCTION AND NUCLEONIC PARAMETERS

The three valance quark wave function can be written as

$$\Psi = \Phi[|\Phi\rangle|\chi\rangle|\Psi\rangle]|\xi\rangle \tag{3.16}$$

Where $|\Phi\rangle$, $|\chi\rangle$, $|\Psi\rangle$ and $|\xi\rangle$ denote the flavour , spin, colour and space time q^3 wave functions. For the lowest lying hadrons, quarks appear to be in S-wave state and the space-time q^3 wave function $|\xi\rangle$ is totally symmetric under the permutation of any two quarks. Hence, the flavour-spin-color part Φ should be totally anti-symmetric under the $q_i \leftrightarrow q_j$.

In conventional quark model, the colour wave function Ψ is taken to be total anti-symmetric , i.e. a colour singlet. But in general this is not necessary if baryon is considered to have a sea component in addition to the q^3 . let subscripts S and A denote the total permutation symmetry and anti-symmetry and λ and ρ denote the symmetry and anti-symmetry under quark permutation $q_1 \leftrightarrow q_2$. Then the q^3 wave function for flavour octet baryons are

1. $\Phi_1^{\frac{1}{2}} \equiv \Phi(8,\frac{1}{2},1_c)=F_S\Psi_1^A$ (3.17)

   Where $F_S=\frac{1}{\sqrt{2}}(\Phi^\lambda\chi^\lambda + \Phi^\rho\chi^\rho)$

2. $\Phi_8^{\frac{1}{2}} \equiv \Phi\left(8,\frac{1}{2},8_c\right) = \frac{1}{\sqrt{2}}(F_{MS}\Psi_8^\rho - F_{MA}\Psi_8^\lambda)$ (3.18)

   Where $F_{MS} = \frac{1}{\sqrt{2}}(\Phi^\rho\chi^\rho - \Phi^\lambda\chi^\lambda)$

   $F_{MA} = \frac{1}{\sqrt{2}}(\Phi^\rho\chi^\lambda + \Phi^\lambda\chi^\rho)$

3. $\Phi_{10}^{\frac{1}{2}} \equiv \Phi(8,\frac{1}{2},10_c)=F_A\Psi_{10}^S$ (3.19)

   Where $F_A = \frac{1}{\sqrt{2}}(\Phi^\lambda\chi^\rho - \Phi^\rho\chi^\lambda)$

4. $\Phi_8^{\frac{3}{2}} \equiv \Phi(8,\frac{3}{2},8_c)=F_A'\chi^{\frac{3}{2}}$ (3.20)

   Where $F_A' = \frac{1}{\sqrt{2}}(\Phi^\lambda\Psi^\rho - \Phi^\rho\Psi^\lambda)$

Now we consider a flavourless sea, which has spin (0,1,2, if we assume sea in S-wave state) and colour $(1_c, 8_c, \overline{10_c})$.

Let $H_{0,1,2}$ and $G_{1,8,\overline{10}}$ and denote spin and colour sea wave function, which satisfy

$$\langle H_i|H_j\rangle = \delta_{ij},\ \langle G_k|G_l\rangle = \delta_{kl} \tag{3.21}$$

The possible combinations of q^3 and sea wave functions which can give a spin $\frac{1}{2}$, flavour octet, colour singlet state, are

$$\Phi_1^{\frac{1}{2}}H_0G_1,\ \Phi_8^{\frac{1}{2}}H_0G_1,\ \Phi_{10}^{\frac{1}{2}}H_0G_{\overline{10}},\ \Phi_1^{\frac{1}{2}}H_1G_1,\ \Phi_8^{\frac{1}{2}}H_1G_8,\ \Phi_{10}^{\frac{1}{2}}H_1G_{\overline{10}} \text{ and } \Phi_8^{\frac{3}{2}}H_1G_8,\ \Phi_8^{\frac{3}{2}}H_2G_8 \tag{3.22}$$

The total flavour-spin-colour wave function of a spin up baryon which consist of three-valence quarks and a sea components can be written as

$$\left|\Phi_{\frac{1}{2}}^{\uparrow}\right\rangle = \frac{1}{N}[\Phi_1^{(\frac{1}{2})^{\uparrow}} H_0 G_1 + a_8 \Phi_8^{(\frac{1}{2})^{\uparrow}} H_0 G_8 + a_{10} \Phi_{10}^{(\frac{1}{2})^{\uparrow}} H_0 G_{\overline{10}} + b_1 \left[\Phi_1^{\frac{1}{2}} \otimes H_1\right]^{\uparrow} G_1 +$$

$$+ b_8 \left(\Phi_8^{\frac{1}{2}} \otimes H_1\right)^{\uparrow} G_8 + b_{10} \left(\Phi_{10}^{\frac{1}{2}} \otimes H_1\right)^{\uparrow} G_{\overline{10}} + c_8 (\Phi_8^{\frac{3}{2}} \otimes H_1)^{\uparrow} G_8 + d_8 (\Phi_8^{\frac{3}{2}} \otimes H_2)^{\uparrow} G_8] \qquad (3.23)$$

Where

$$N^2 = 1 + a_8^2 + a_{10}^2 + b_1^2 + b_8^2 + b_{10}^2 + c_8^2 + d_8^2 \qquad (3.24)$$

The first three terms in (3.23) come from a spin $\frac{1}{2}$, q^3 state coupled to a spin 0(scalar) sea. The next three terms in (3.23) come from spin $\frac{1}{2}$ $q^3 \otimes$ spin 1 (vector) sea and have

$$(\Phi_1^{\frac{1}{2}} \otimes H_1)^{\uparrow} \equiv \Phi_{b1}^{(\frac{1}{2})^{\uparrow}} \Psi_1^A \qquad (3.25)$$

$$(\Phi_8^{\frac{1}{2}} \otimes H_1)^{\uparrow} \equiv \Phi_{b8}^{(\frac{1}{2})^{\uparrow}} \qquad (3.26)$$

$$(\Phi_{10}^{\frac{1}{2}} \otimes H_1)^{\uparrow} \equiv \Phi_{b10}^{(\frac{1}{2})^{\uparrow}} \Psi_{10}^S \qquad (3.27)$$

Where

$$\Phi_{b1}^{(\frac{1}{2})^{\uparrow}} = \sqrt{\tfrac{2}{3}} H_{1,1} F_S^{(\frac{1}{2})^{\downarrow}} - \sqrt{\tfrac{1}{3}} H_{1,0} F_S^{(\frac{1}{2})^{\uparrow}} \qquad (3.28)$$

$$\Phi_{b8}^{(\frac{1}{2})^{\uparrow}} = \sqrt{\tfrac{1}{2}} [\Phi_{b8S}^{(\frac{1}{2})^{\uparrow}} \Psi_8^{\rho} - \Phi_{b8A}^{(\frac{1}{2})^{\uparrow}} \Psi_8^{\lambda}] \qquad (3.29)$$

$$\Phi_{b10}^{(\frac{1}{2})^{\uparrow}} = \sqrt{\tfrac{2}{3}} H_{1,1} F_A^{(\frac{1}{2})^{\downarrow}} - \sqrt{\tfrac{1}{3}} H_{1,0} F_A^{(\frac{1}{2})^{\uparrow}} \qquad (3.30)$$

In equation (3.29),

$$\Phi_{b8S}^{(\frac{1}{2})^{\uparrow}} = \sqrt{\tfrac{2}{3}}\ H_{1,1} F_{MS}^{(\frac{1}{2})^{\downarrow}} - \sqrt{\tfrac{1}{3}} H_{1,0} F_{MS}^{(\frac{1}{2})^{\uparrow}} \qquad (3.31)$$

$$\Phi_{b8A}^{(\frac{1}{2})^{\uparrow}} = \sqrt{\tfrac{2}{3}}\ H_{1,1} F_{MA}^{(\frac{1}{2})^{\downarrow}} - \sqrt{\tfrac{1}{3}} H_{1,0} F_{MA}^{(\frac{1}{2})^{\uparrow}} \qquad (3.32)$$

The final two ($c_{8,} d_8$) terms in (3.23) come from spin $\frac{3}{2}$ (q^3) $\otimes$ spin 1(vector sea) and spin $\frac{3}{2}$ $(q^3)\otimes$ spin 2 (tensor sea) resp. Their expressions are

$$(\Phi_8^{(\frac{3}{2})} \otimes H_1)^{\uparrow} \equiv \Phi_{c8}^{(\frac{1}{2})^{\uparrow}} \tag{3.33}$$

$$(\Phi_8^{\frac{3}{2}} \otimes H_2)^{\uparrow} \equiv \Phi_{d8}^{(\frac{1}{2})^{\uparrow}} \tag{3.34}$$

Where

$$\Phi_{c8}^{(\frac{1}{2})^{\uparrow}} = [\sqrt{\tfrac{1}{2}}\, H_{1,-1}\chi_{\frac{3}{2}}^{\frac{3}{2}} - \sqrt{\tfrac{1}{3}}\, H_{1,0}\chi_{\frac{1}{2}}^{\frac{3}{2}} + \sqrt{\tfrac{1}{6}}\, H_{1,1}\chi_{\frac{-1}{2}}^{\frac{3}{2}}]F_A' \tag{3.35}$$

$$\Phi_{d8}^{(\frac{1}{2})^{\uparrow}} = [\sqrt{\tfrac{2}{3}}\, H_{2,2}\chi_{-\frac{3}{2}}^{\frac{3}{2}} - \sqrt{\tfrac{3}{10}}\, H_{2,1}\chi_{-\frac{1}{2}}^{\frac{3}{2}} + \sqrt{\tfrac{1}{5}}\, H_{2,1}\chi_{\frac{1}{2}}^{\frac{3}{2}} - \sqrt{\tfrac{1}{10}}\, H_{2,-1}\chi_{\frac{3}{2}}^{\frac{3}{2}}]\, F_A' \tag{3.36}$$

Here, we suggest a possible way to construct the sea wave function using the statistical model of Zhang et al [5]. However, unlike Ref. [6], we will also take into account the "active" sea contribution of the sea in which the relevant operators act on the sea quarks as well. Furthermore, we will use an approximation in which quarks in the q^3 core will not be antisymmetrized with the identical quarks appearing in the sea. Use of different labels for valance and sea quarks has been justified with the assumption that the valance and the sea quarks have very different momentum distributions, with the valance quarks being "hard" and the sea quarks "soft", and that the overlap region between the two momentum distributions is negligible [7].

Next, we decompose each one of the Fock states |uud, *i*, *j*, *k*⟩ in terms of the set of states appearing in equation (3.12) following a statistical approach.

(i) Consider the decomposition of a state |uud, 0, 0, 2⟩ or |gg⟩ sea (two gluons in the sea).

Spin: uud: 1/2 ⊗ 1/2 ⊗ 1/2 = 2*(*1/2*)* ⊕ 3/2,

gg: 1 ⊗ 1 = 0s ⊕ 1a ⊕ 2s,

Colour: uud: 3 ⊗ 3 ⊗ 3 = 1 ⊕ 8 ⊕ 8 ⊕ 10,

gg: 8 ⊗ 8 = 1s ⊕ 8s ⊕ 8a ⊕ 10a ⊕ 10a ⊕ 27s.

The subscripts s and a denote symmetry and asymmetry, respectively, under the exchange of two identical bosons (gluons above). Call ρ_{j_1,j_2} as the probability that the q^3 core and gg sea are in angular momentum states j_1 and j_2, respectively, and they finally add to give total angular momentum 1/2. Let us compare such probabilities:

$$\frac{\rho_{1/2\ 0_s}}{\rho_{1/2\ 1_a}} = \frac{(4/8).(1/9).1}{(4/8).(3/9).(2/6)} = 1$$

$$\frac{\rho_{1/2\ 0_s}}{\rho_{3/2\ 2_s}} = \frac{(4/8).(1/9).1}{(4/8).(5/9).(2/20)} = 2$$

$$\frac{\rho_{3/2\ 1_a}}{\rho_{3/2\ 2_s}} = \frac{(4/8).(3/9).(2/6)}{(4/8).(5/9).(2/20)} = 1$$

$$\frac{\rho_{1/2\ 1_a}}{\rho_{3/2\ 1_a}} = \frac{(4/8).(3/9).(2/6)}{(4/8).(3/9).(2/12)} = 2$$

The first factor in the numerator or denominator in the r.h.s is the relative probability for the core quarks to have spin j_1 , the second factor is the same for the gluons to have spin j_2 and finally the third one is the same for j_1 and j_2 to have resultant $\frac{1}{2}$.

Similarly we can compare the probabilities for the q^3 core and gg to be in different color substate which finally give a color singlet proton. In obvious notations:

$$\frac{\rho_{1\ 1_s}}{\rho_{8\ 8_s}} = \frac{(1/27).(1/64).1}{(16/27).(8/64).(1/64)} = \frac{1}{2} = \rho_{1\ 1_s}/\rho_{8\ 8_a}$$

$$\frac{\rho_{1\ 1_s}}{\rho_{10\ \overline{10}}} = \frac{(1/27).(1/64).1}{(10/27).(10/64).(1/100)} = 1$$

The product of probabilities in spin and color space can be written in terms of common parameter c as

$$\rho_{\frac{1}{2}\ 0_s}\left[\rho_{1\ 1_s}, \rho_{8\ 8_s}\right] = 2c(1,2)$$

$$\rho_{\frac{1}{2}}\left[\rho_{8\ 8_a},\ \rho_{10\ \overline{10}}\right] = 2c(2,1)$$

$$\rho_{\frac{3}{2}\ 1_a}\left[\rho_{8\ 8_a}\right] = 2c$$

$$\rho_{\frac{3}{2}\ 2_s}\left[\rho_{8\ 8_s}\right] = 2c$$

There is no contribution to $H_0G_{\overline{10}}$ and H_1G_1 sea from two gluon states because H_0 and G_1 are symmetric whereas H_1 and $G_{\overline{10}}$ are anti-symmetric under the exchange of two gluons making these product wave functions anti-symmetric and hence unacceptable for the bosonic system. The sum of probabilities is taken from the reference [5] and this determines the unknown parameter c,

$$\rho_{uudgg} = 0.081887, c = 0.005118$$

This gives us above product of probabilities for finding the fock state with two gluons in the sea in various substates with specified spin and color quantum numbers. Thus, for instance $\rho_{\frac{1}{2}\ 0_s}\rho_{1 1_s}$ =0.01024 means that the probabilities for finding the three quark core in spin $\frac{1}{2}$ and color singlet state along with the two gluon sea to be in a scalar and color singlet state is 0.01024.

Similar decomposition will hold good for $|\bar{q}q\bar{q}q$ sea also. By proceeding on the similar lines, we get

$\rho_{\frac{1}{2}\ 0_s}[\rho_{1 1_s}, \rho_{8\ 8_s}]; \rho_{\frac{1}{2}\ 1_a}[\rho_{8\ 8_a}, \rho_{10\ \overline{10}}]; \rho_{\frac{3}{2}\ 1_a}[\rho_{8\ 8_a}]; \rho_{\frac{3}{2}\ 2_s}[\rho_{8\ 8_s}]$

= 0.000904(1,2;2,1;2;2) for $|\bar{u}u\bar{u}u\rangle$,

=0.014571(1,2;2,1;2;2) for $|\bar{d}d\bar{d}d\rangle$.

Table for relative probability density and value of c for different states:

states	Relative probability	Value of c	Values of n for different values of c							
			H_0G_1	H_0G_8	$H_0G_{\overline{10}}$	H_1G_1	H_1G_*	$H_1G_{\overline{10}}$	H_2G_8	H_1G_8
$\vert gg\rangle$	0.081887	0.0051179	2	4	0	0	4	2	2	2
$\vert \bar{d}dg\rangle$	0.082708	0.0025850	2	8	2	2	8	2	4	4
$\vert \bar{u}u\bar{d}d\rangle$	0.029306	0.0009158	2	8	2	2	8	2	4	4
$\vert \bar{d}d\bar{d}d\rangle$	0.014570	0.0009106	2	4	0	0	4	2	2	2
$\vert ggg\rangle$	0.032056	0.0045794	1	4	4	1	2	12	8	24
$\vert \bar{u}u\bar{d}dg\rangle$	0.030569	0.0004776	1	2	2	3	24	6	8	12
$\vert \bar{d}d\bar{d}dg\rangle$	0.015242	0.0001270	2	16	4	6	48	12	8	24
$\vert \bar{u}ugg\rangle$	0.030419	0.0002535	2	16	4	6	48	12	8	24
$\vert \bar{d}dgg\rangle$	0.045441	0.0003787	2	16	4	6	48	12	8	24
$\vert \bar{u}u\bar{u}u\rangle$	0.007231	0.0004519	2	4	0	0	4	2	2	2
$\vert \bar{u}u\bar{u}ug\rangle$	0.007642	0.0000368	2	16	4	6	48	12	8	24
$\vert \bar{u}ug\rangle$	0.054978	0.0017181	2	8	2	2	8	2	4	4

(ii) for decomposition of $|g\bar{q}q\rangle$ and $|\bar{u}u\bar{d}d\rangle$ sea, symmetry consideration is not needed. Here we have assumed that $\bar{q}q$ carries the quantum number of a gluon due to sub processes g$\leftrightarrow$ $\bar{q}q$. Thus the relative probability density in color space is $\rho_{1\ 1}/\rho_{8\ 8}= 1/4$.

The ratio $\rho_{1\ 1}/\rho_{10\ \overline{10}}$ and the relative densities in spin space remain the same as in (i). Proceeding as in the previous case, the product of densities in spin and color spaces come out as

$$\rho_{\frac{1}{2}\ 0}[\rho_{1\ 1}, \rho_{8\ 8}, \rho_{10\ \overline{10}}];\ \rho_{\frac{1}{2}\ 1}[\rho_{1\ 1}, \rho_{8\ 8}, \rho_{10\ \overline{10}}];\ \rho_{\frac{3}{2}\ 1}[\rho_{8\ 8}];\ \rho_{\frac{3}{2}\ 2}[\rho_{8\ 8}]$$

= 0.0034(1,4,1;1,4,1;2;2) for $|g,\bar{u}u\rangle$,

= 0.00517(1,4,1;1,4,1;2;2) for $|g,\bar{d}d\rangle$,

= 0.00366(1,4,1;1,4,1;2;2) for $|\bar{u}u, \bar{d}d\rangle$.

(iii) $|gg\bar{q}q\rangle$, $|\bar{q}q\bar{q}qg\rangle$ sea: first we take the product of two spin states and two color octet states as in (i). These are further multiplied with spin 1 and color octet state resp. The new results needed are

Spin : $1\otimes 2= 1\oplus 2\oplus 3$

Color: $10\otimes 8 = 8\oplus 10\oplus 27\oplus 35$

$27\oplus 8 = 8\oplus 10\oplus \overline{10}\oplus 2(27)\oplus 35\oplus 35\oplus 64$

Using the subscript s and a for the symmetry and asymmetry under the exchange of first two bosons, the relative probability densities in spin space are:

$$\frac{\rho_{\frac{1}{2}\ 0_a}}{\rho_{\frac{1}{2}\ 1_a}} = \frac{(1/27).1}{(3/27).(2/6)} = 1$$

$$\frac{\rho_{\frac{1}{2}\ 0_a}}{\rho_{\frac{1}{2}\ 1_s}} = \frac{(1/27).1}{(6/27).(4/12)} = \frac{1}{2}$$

$$\frac{\rho_{\frac{1}{2}\ 1_a}}{\rho_{\frac{3}{2}\ 1_a}} = \frac{(3/27).(1/3)}{(3/27).(1/6)} = 2 = \frac{\rho_{\frac{1}{2}\ 1_s}}{\rho_{\frac{3}{2}\ 1_s}}$$

The ratios of the probability densities in color space are:

$$\frac{\rho_{1\ 1_s}}{\rho_{8\ 8_s}} = \frac{(1/27).(1/512).1}{(16/27).(32/512).(1/64)} = \frac{1}{8}$$

$$\frac{\rho_{1\ 1_s}}{\rho_{10\ \overline{10}_s}} = \frac{(1/27).(1/512)1}{(10/27).(20/512).(1/100)} = \frac{1}{2} = \rho_{1\ 1_a}/\rho_{10\ \overline{10}_a}$$

$$\frac{\rho_{1\ 1_a}}{\rho_{8\ 8_a}} = \frac{(1/27).(1/512).1}{(16/27).(32/512)(1/64)} = \frac{1}{8}$$

The combined probabilities in spin and color space can be written as

$\rho_{\frac{1}{2}\ 0_a}[\rho_{1\ 1_a}, \rho_{8\ 8_a}, \rho_{10\ \overline{10}_a}]$; $\rho_{\frac{1}{2}\ 1_a}[\rho_{1\ 1_a}, \rho_{8\ 8_a}, \rho_{10\ \overline{10}_a}]$; $\rho_{\frac{1}{2}\ 1_s}[\rho_{1\ 1_s}, \rho_{8\ 8_s}, \rho_{10\ \overline{10}_s}]$; $\rho_{\frac{3}{2}\ 1_a}[\rho_{8\ 8_a}]$;
$\rho_{\frac{3}{2}\ 1_a}[\rho_{8\ 8_s}]$ = 0.00051(1,8,2;1,8,2;2,16,4;4;8;4) for |gg,$\bar{u}u$⟩,

= 0.00076(1,8,2;1,8,2;2;2,2,16,4;4;8;4) for |gg,$\bar{d}d$⟩,

= 0.00007(1,8,2;1,8,2;2,16,4;4;8;4) for |$\bar{u}u\bar{u}u$,g⟩,

= 0.00025(1,8,2;1,8,2;2,16,4;4;8;4) for |$\bar{d}d\bar{d}d$,g⟩.

(iv) |$\bar{u}u\bar{d}d$g⟩sea: here there is no symmetry requirement. Ratios of probability densities are

$\frac{\rho_{\frac{1}{2}\ 0}}{\rho_{\frac{1}{2}\ 1}} = \frac{1}{3}$, $\frac{\rho_{\frac{1}{2}\ 0}}{\rho_{\frac{3}{2}\ 1}} = 1$, $\frac{\rho_{\frac{1}{2}\ 1}}{\rho_{\frac{3}{2}\ 1}} = 2$, $\frac{\rho_{\frac{3}{2}\ 1}}{\rho_{\frac{3}{2}\ 2}} = \frac{3}{2}$, in spin space and

There products can be written as

$$\rho_{\frac{1}{2}\ 0}[\rho_{1\ 1}, \rho_{8\ 8}, \rho_{10\ \overline{10}}];\ \rho_{\frac{1}{2}\ 1}[\rho_{1\ 1}, \rho_{8\ 8}, \rho_{10\ \overline{10}}]; \rho_{\frac{3}{2}\ 2}[\rho_{8\ 8}];\ \rho_{\frac{3}{2}\ 2}[\rho_{8\ 8}]$$

=0.00048(1,8,2;3,24,6;12;8).

(v) |ggg⟩ sea:

The wave function for this sea should be completely symmetric under the exchange of any two gluons . Among the product spin function, the total spin S= 0 is completely anti-symmetric and one S=1 is completely symmetric. Among the product color functions, there is one color singlet state and one color octet state which are completely anti-symmetric; and there is one color singlet state and one color octet state which are completely symmetric.

This gives,

$$\frac{\rho_{\frac{1}{2}\ 0}}{\rho_{\frac{1}{2}\ 1}} = 1, \qquad \frac{\rho_{\frac{1}{2}\ 1}}{\rho_{\frac{3}{2}\ 1}} = 2, \qquad \frac{\rho_{1\ 1_{a,s}}}{\rho_{8\ 8}} = \frac{1}{2}$$

This gives us the product of probabilities in spins and color space as

$$\rho_{\frac{1}{2}\ 0_a}\left[\rho_{1\ 1_a}, \rho_{8\ 8_a}\right];\ \rho_{\frac{1}{2}\ 1_s}\left[\rho_{1\ 1_s}, \rho_{8\ 8_s}\right];\ \rho_{\frac{3}{2}\ 1_s}\left[\rho_{8\ 8_s}\right] = 0.00457943(1,2;1,2;1)$$

A confined gluon in the sea may be divided into TE (transverse electric) modes with $J^{PC} = 1^+$ and the TM (transverse magnetic) modes with J^{PC}=1^-. The Fock states with a single gluon in the sea may be considered to be consisting of a TE gluon [8]. Clearly a gluon in the sea will contribute only to the H_1G_8 component of the following numbers for the coefficients in the expansion in eq.(1) of the proton state.

The sum of probability densities for the state H_0G_8 comes to be 0.0282471.

Similarly, we can find the probability densities for states $H_0G_{\overline{10}}$, H_1G_1 , H_1G_8 , $H_1G_{\overline{10}}$, and H_2G_8.

On solving the total flavour–spin –colour wave function of a spin up baryon which consist of three valence quarks and sea components by first calculating the probability density for each of the different states: $H_0G_1, H_0G_8, H_0G_{\overline{10}},\ H_1G_1, H_1G_8, H_1G_{\overline{10}}\ and\ H_2G_8$;

Table: Value of 'nc' calculated using the relative probability for different states.

states	H_0G_1	H_0G_8	$H_0G_{\overline{10}}$	H_1G_1	$H_1G_8^{\frac{1}{2}}$	$H_1G_{\overline{10}}$	H_2G_8	$H_1G_8^{\frac{3}{2}}$
$\vert gg\rangle$	0.0102360	0.0201716	0	0	0.0204716	0.0102358	0.0102360	0.0102360
$\vert \bar{u}ug\rangle$	0.0034362	0.0137448	0.0034362	0.0034362	0.0137448	0.0034362	0.0068730	0.0068730
$\vert \bar{d}dg\rangle$	0.0051700	0.0206800	0.0051700	0.0051700	0.0206800	0.0051700	0.0103400	0.0103400
$\vert \bar{u}u\bar{d}d\rangle$	0.0018316	0.0073264	0.0018316	0.0018320	0.0073264	0.0018316	0.0036632	0.0036632
$\vert \bar{d}d\bar{d}d\rangle$	0.0018213	0.0036430	0	0	0.0036425	0.0018213	0.0018212	0.0018213
$\vert ggg\rangle$	0.0045794	0.0091588	0	0.0045794	0.0091588	0	0	0.
$\vert \bar{u}u\bar{d}dg\rangle$	0.0004776	0.0038208	0.0009552	0.0014328	0.0114624	0.0028656	0.0038208	0.0057312
$\vert \bar{d}d\bar{d}dg\rangle$	0.0002540	0.0020323	0.0005081	0.0007621	0.0060960	0.0015240	0.0010160	0.0030485
$\vert \bar{u}ugg\rangle$	0.0005070	0.0040560	0.0010400	0.0015210	0.01268	0.0030421	0.0020280	0.0060840
$\vert \bar{d}dgg\rangle$	0.0007574	0.0060592	0.0015148	0.0022722	0.018178	0.0045440	0.0030296	0.0090890
$\vert \bar{u}u\bar{u}u\rangle$	0.0009039	0.0018078	0	0	0.0018077	0.0009039	0.0009039	0.0009038
$\vert \bar{u}u\bar{u}ug\rangle$	0.0001273	0.0010189	0.0002547	0.0003820	0.0030567	0.0007641	0.0005094	0.0015283
$\vert 0\rangle$	0.1487930	-	-	-	-	-	-	-
$\vert g\rangle + \vert \bar{u}u\rangle + \vert \bar{d}d\rangle$	-	-	-	-	0.1880580	-	-	0.0940290
Total	0.1788946	0.0935196	0.0146846	0.0213878	0.3165194	0.0361386	0.0442411	0.1525338

The total flavor-spin-color wave function of a spin up proton can be written as:

$|\Phi_{\frac{1}{2}}^{\uparrow}\rangle = \frac{1}{N'}[\sqrt{0.1788946}\Phi_1^{\frac{1}{2}\uparrow} H_0 G_1 + \sqrt{0.0935196}\Phi_8^{\frac{1}{2}\uparrow} H_0 G_8 + \sqrt{0.0146846} H_0 G_{\overline{10}} +$

$\sqrt{0.0213878}\left(\Phi_1^{\frac{1}{2}} \otimes H_1\right)^{\uparrow} G_1 + \sqrt{0.3165194}\left(\Phi_8^{\frac{1}{2}} \otimes H_1\right)[^{\uparrow} G_8 + \sqrt{0.0361386}\left(\Phi_{10}^{\frac{1}{2}} \otimes H_1\right)^{\uparrow} G_{\overline{10}} +$

$\sqrt{0.0442411}(\Phi_8^{\frac{3}{2}} \otimes H_2)^{\uparrow} G_8 + \sqrt{0.15253388}(\Phi_8^{\frac{3}{2}} \otimes H_1)^{\uparrow} G_8]$

Where,

$$a_0 = \sqrt{0.1788946}\ , a_8 = \sqrt{0.0935196}\ , a_{10} = \sqrt{0.0146846}\ , b_1 = \sqrt{0.0213878}\ , b_8 = \sqrt{0.3165194}\, , b_{10} = \sqrt{0.0361386}\, , c_8 = \sqrt{0.15253388}\, , d_8 = \sqrt{0.0442411}$$

Thus N'^2 = 0.85791904

Also, N^2 = 4.79

Also we define five parameters as in ref. [2] as,

$a^* = \frac{1}{2}[1 - \frac{b_1^2}{3}]$ =0.480047

$b^* = \frac{1}{4}\left[a_8^2 - \frac{b_8^2}{3}\right] = \ -0.0167260$

$c^* = \frac{1}{2}\left[a_{10}^2 - \frac{b_{10}^2}{3}\right] = \ 0.007222956$

$d^* = \frac{1}{18}[5c_8^2 - 3d_8^2] = \ 0.0.195429$

$e^* = \frac{\sqrt{2}}{3} b_8 c_8$ = 0.57869

For calculating physical quantities related to the spin of a nucleon, it is useful to introduce two parameters, $\propto$ and β as in [9],

$\propto = (\frac{1}{N^2})(\frac{4}{9})(2a + 2b + 3d + \sqrt{2}e)$ =0.216114

$\beta = (\frac{1}{N^2})(\frac{1}{9})(2a - 4b - 6c - 6d + 4\sqrt{2}e)$= 0.0714872

The physical reasons is that $\propto$ and β are connected with the number of spin up [n($q_\uparrow$)] and spin down [n($q_\downarrow$)] quarks in the spin up proton.

If, $\Delta q = n(q_\uparrow) - n(q_\downarrow) + n(\bar{q}_\uparrow) - n(\bar{q}_\downarrow)$, $q = u, d, s$ then $\Delta u = 3 \propto$ and $\Delta d = -3\beta$. This can be directly checked from the wavefunction given in (3.12). Also, as there are no explicit antiquarks no explicit antiquarks or S quarks in the wave functions, n($\bar{q}_\uparrow$) $- n(\bar{q}_\downarrow) = 0$ and $\Delta S = 0$.

3.4 LOW ENERGY PROPERTIES OF PROTON

The total spin of the nucleon spin from the spins of the quarks, denoted by I_1^P and I_1^N, have been calculated and compared with the revised EMC results [5]. We should note that the EMC value is for $Q^2 \approx 10\ GeV^2$, whereas our results for I_1^P and I_1^N should be considered to work at $Q^2 \approx 1GeV^2$, where the Fock state decomposition of the nucleon state [3] used in the applies. The value of I_1^P and I_1^N is calculated from $\propto$ and β using ref. [2] as:-

$$I_1^P = \frac{1}{6(4\alpha - \beta)} = 0.132$$

$$I_1^N = 1/6(\alpha\text{-}4\beta) = -0.0116$$

To estimate ($\frac{g_A}{g_V}$) we use Bjorken sum rule,

$$(g_1^P - g_1^N) = \text{dx}\ (g_1^P(x) - g_1^N(x))$$

$$= \frac{1}{6} \left| \frac{g_A}{g_V} \right| [1\text{-}\frac{\propto_S Q^2}{\pi}]$$

By using $\propto$ and β, we can also find the ratio $\frac{g_A}{g_V}$ (weak- decay constant) for n→p [2] as,

$$\frac{g_A}{g_V} = 1.51$$

The ${}^F/_D$ value has been obtained from $\propto$ and β as per the prescription given in the ref [2].

$$\frac{F}{D} = \frac{\propto}{\propto + 2\beta} = 0.60184$$

Also the ratio of magnetic moment of nucleons is calculated using the values of $\propto$ and β using the relation,

$$\frac{\mu_P}{\mu_N} = -\frac{2\propto+\beta}{\propto+2\beta} = -1.40$$

In view of these phenomenological evidences, it appears reasonable to propose that higher multiplicity states are suppressed. We parameterize this suppression in a simple way by assuming that probability of a system to be in a spin and color state is inversely proportional to the multiplicity (both in spin and color spaces) of the state.

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4.1 SUMMARY AND CONCLUSION

Here we have calculated the various properties of nucleon like weak-decay content, spin –content of nucleon, ratio of magnetic moments for nucleon i.e. $\frac{g_A}{g_V}$, $\frac{F}{D}$ and $\frac{\mu_P}{\mu_N}$ by treating quark-gluon Fock states as decomposed of states in which three quarks and other stuff (quark-anti quark and gluon states known as sea) have a definite spin and color quantum numbers, considering sea-part as flavorless. Moreover, each sub-state of a nucleon is considered to be in an equal probability assuming quarks and gluons as non-relativistic particles moving in S-wave. Here we have limited the contributions from states with u and d quarks only not from s-quark in the sea.

Our results of calculation holds good for a typical hadronic energy scale~1 GeV^2.