Strangeness in proton and properties of nucleons in nuclear matter revisited

Abstract The properties of the nucleons in nuclear medium have been investigated in the context of the flux tube model incorporating strangeness ($s\bar{s}$) contribution to proton structure in conformity with the experimental indication. Proton is described as a pentaquark system with strange quark contribution whereas neutron is described in three quark configuration. The Quasi particle model of diquark is used to describe the structures of the nucleons. Modifications of the properties like swelling, mass, incompressibility, ratio of the structure functions ($\frac{F_n(x)}{F_p(x)}$), Gottfried Sum rule for nucleons in nuclear medium have been studied and significant effects have been observed. It has been suggested that the change of the size degree of freedom of the nucleon in the nuclear medium plays an important role in describing the properties in medium. The results are discussed in detail and compared with existing experimental and theoretical predictions. Some interesting observations are made.

keywords Structure Function.Gottfried Sum Rule.Diquark.Quasi Particle

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1. Introduction

The modification of the internal structure of nucleons in the nuclear environment was studied by European Muon Collaboration (EMC)[1]. The experiment predicted the swelling of the nucleon in nuclear matter and has observed that the properties of the nucleon in nuclear matter differ substantially from that of a free nucleon. The swelling is largely interpreted as the effect of attraction of neighbouring quarks to the quarks constituting the nucleon. Recently Seely et al [2] have reported that the modification of the particle properties primarily depend on the immediate neighborhood within nucleus and not on the mass or density of the nucleus. Wu et al [3] have studied the modification of the properties of the nucleon in nuclear matter and in finite nuclei describing the nucleon as non-topological solitons. They have considered that the quarks inside the soliton bag not only couple to the scalar field that binds the quarks together into nucleons but also to the additional meson field generated by nuclear environment. Kim et al.[4] have studied the swollen of nucleon in nuclear matter for (e,e’p)reaction. They have incorporated the effect to the form factors containing the anomalous magnetic moment of the nucleons and studied the effect by exchanging the form factors of the free nucleons by those of the nucleons in nuclear matter. Recently Rozynek [5] has studied the modification of the nucleon structure function in nuclear matter in the context of relativistic mean field(RMF) approach. Higinbotham et al [6] have investigated the nuclear short range correlation (SRC) and the EMC Effect using the observed phenomenological relationships. They have suggested that the correlation between the EMC and the SRC is dominated by the high momentum nucleons in the nucleus.

Recent experiments have suggested [7] a strange contribution to the proton magnetic moment. It has been observed that the fraction of the spin of the proton carried by quarks is small and a substantial contribution comes from the strange quark-antiquarks (s$\bar{s}$). A number of works have been done on the strangeness contribution to the proton structure. Zou et al [8] have investigated the strangeness contribution to the proton magnetic moment considering the proton as a [uuds$\bar{s}$] system. Riska et al [9] have investigated the magnetic form factor of the proton in uuds$\bar{s}$ configuration. They have pointed out that empirical strange form fac-
observed that the transition matrix element between uud and uuds\overline{s} components gives significant contribution. An et al [10] have studied uuds\overline{s} configuration of proton and have investigated the strangeness magnetic moment considering one of the constituent quarks in excited state. They have observed a significant contribution in qqqq\overline{q} in baryon and have revealed the possibility of the colored cluster configuration (diquarks) rather than the 'meson cloud' configuration.

In the present work we have studied the modification of the properties of the nucleons in nuclear media incorporating a strange quark contribution to the proton structure. The proton has been considered as a five quark system with a s\overline{s} contribution and supposed to have a pentaquark configuration like [uuds\overline{s}] such as [ud][us]\overline{s}\overline{s} where [ud] and [ud] are scalar diquarks of corresponding flavours. We have treated intrinsic sea contribution s\overline{s} valence like. In this context it may be mentioned that recently An et al [10] have pointed out that the contribution from intrinsic sea is much more valence like particularly at large x- region. The neutron has been considered in usual diquark-quark system [[(ud)\overline{d}]]. It would be interesting to investigate the fact that how the incorporation of strange quark degrees of freedom to the proton and diquark-diquark-anti quark configuration reproduces the properties of the proton in nuclear medium. A comparison between the properties of the neutron and the proton in medium have been studied. The quasi particle model for diquark [11] has been used to estimate effective mass of diquarks. The effect of the nuclear medium on the properties like the radius, the compressibility, Roper resonance of nucleons have been investigated through the change of the radii of the nucleons in nuclear medium. The variation of the \frac{F_{qg}(x)}{F_{qg}(x)} and the Gottfried sum rule in nuclear medium have been studied. So far most of the studies of the structure functions of nucleons are done for the free nucleons. It would be interesting to investigate how the swollen of the nucleons in nuclear medium affects the structure functions. It is interesting to observe in the current investigation that the pentaquark configuration of the proton is consistent with the \overline{u}-d asymmetry in the nucleon sea distribution.

2. The Model
to be correlated to form a low energy configuration, a diquark. Diquarks are supposed to behave like a quasi particle in an analogy with an electron in the crystal lattice which behaves as a quasi particle [12]. It is well known that a quasi particle is a low-lying excited state whose motion is modified by the interactions within the system. An electron in a crystal is subjected to two types of forces, namely, the effect of the crystal field (\(\nabla V\)) and an external force (F) which accelerates the electron [12]. Under the influence of these two forces, an electron in a crystal behaves like a quasi particle having velocity \(v\) whose effective mass \(m^*\) reflects the inertia of electrons which are already in a crystal field. The effective mass can be represented as:

\[
m^* \frac{dv}{dt} = F
\]  

(1)

Again the bare electrons (with normal mass) are affected by the lattice force \(-\nabla V\) (where \(V\) is periodic potential) and the external force F so that:

\[
m \frac{dv}{dt} = F - \frac{dV}{dx}
\]  

(2)

So the ratio of the normal mass (\(m\)) to the effective mass (\(m^*\)) can be expressed as:

\[
m/m^* = 1 - \frac{1}{F} \left[ \frac{\delta V}{\delta x} \right]
\]  

(3)

An elementary particle in vacuum may be suggested to be in a situation exactly resembling that of an electron in a crystal [12]. We have proposed a similar type of picture for the diquark \([ud]_0\) as a quasi particle inside a nucleon. The strong interaction is characterized by two types of forces. One is short range confinement force and the other one is the asymptotic freedom. We have assumed that the formation of diquark is favoured by the nature of the vacuum and the two types of forces within the hadrons. The diquark is supposed to behave like an independent hypothetical colour antisymmetric body under the influence of these two types of forces. One is represented by the potential \(V = -\frac{2}{3} \frac{\alpha_s}{r}\) where \(\alpha_s\) is the strong coupling constant and this potential is assumed to resemble the crystal field on a crystal electron. On the other hand we have considered an average force \(F = -ar\) for the external force where 'a' is a suitable constant. It has been assumed that under the influence of these two types of interactions the diquark behaves like a quasi particle, a low-lying excited state and its mass gets modified. The
\[ V_{ij} = -\frac{\alpha}{r} + (F_i F_j)(-\frac{1}{2}Kr^2) \] (4)

Where the coupling constant \( \alpha=(2/3)\alpha_s, F_i, F_j=-(2/3) \), K is the strength parameter. Hence \( V_{ij} \) may be represented as:

\[ V_{ij} = -(2/3)\alpha_s + ar^2 \] (5)

Where \( a=K/3 \).

The ratio of the constituent mass and the effective mass of the diquark \( (m_D) \) has been obtained by using the same formalism as in equation (3) and we arrive at:

\[ \frac{m_q + m_{q'}}{m_D} = 1 + \frac{\alpha_s}{3a r^3} \] (6)

Here \( m_q+m_{q'} \) represents the normal constituent masses of the quarks forming the relevant diquarks and \( m_D \) is the effective mass of the diquark. \( \alpha=\frac{2}{3}\alpha_s \), \( \alpha_s = 0.58 \) [13] and the strength parameter \( a = 0.02 GeV^3 \), 'r' is the radius parameter of the diquark. The radii parameter of the scalar diquarks have been used from existing literature as \( r_{ud} =0.717 \text{ fm}[14], r_{us}=0.616 \text{ fm}[14] \). Using the masses of the constituent quarks \( (m_u=m_d= 0.360 \text{ GeV} \) and \( m_s=0.540 \text{ GeV} )[15] \), we have computed the masses of the \([ud_0]\) and the \([us_0]\) diquarks as \( m_{ud} = 0.590\text{GeV}, m_{us} = 0.674\text{GeV} \) respectively. These diquark masses have been used to investigate the properties of the proton and the neutron in subsequent analysis.

3. Formulation

Mathieu et al.[16] have considered a flux tube model of the nucleons with quark-diquark configuration where the quark and the diquark are linked by the flux tube. The hamiltonian(H) for an isolated nucleon has been represented as,

\[ H = \frac{p^2}{2\mu} + \sigma r - \frac{4\alpha_s}{3r} \] (7)

Where \( \mu \) is the reduced mass of the system, \( p \) is the relative momentum, \( \sigma \) is the string tension and \( \alpha_s \) is the strong coupling constant. It is known that when the nucleon is in the nuclear medium the hamiltonian changes due to the
are topologically arranged in such a way that the linear potential of the system is minimized. When the constituents of two nucleons are very close to each other, the flux tubes are suggested to be redistributed among the constituents to yield a topology where a lowering in total length for the flux tubes occurs. Considering the effect of one perturbing nucleon, the effective modified linear potential [16] may be represented as,

\[ V_{Leff}(r) = \sigma r - \frac{\sigma \rho \pi}{6 2^4} \int |\psi(r')|^2 (t^2 - 4u^2)^2 \theta(t - 2u)d^3r' \] \hspace{1cm} (8)

The one gluon exchanged term would also be modified partially due to the presence of the other nucleons and the effective modified coulomb potential may be represented as in [16]:

\[ V_{Ceff}(r) = -\frac{4\alpha_s}{3r} - \frac{4\alpha_s\rho}{18} \left( \frac{2\pi}{3} \right) \int |\psi(r')|^2 (1 - z')(r^2 - r'^2 - 4rr')d^3r' \] \hspace{1cm} (9)

Where 'r' and 'r'' represent the length of the flux tube for two nucleon clustering as in [16]. \( \Psi(r') \) is the nucleon wave function, \( \rho \) is the nuclear matter density and \( \sigma \) is the string constant. Symbols are used as in Mathieu et al [16]. The total effective potential \( < V > \) between the constituents of a nucleon can be expressed as:

\[ < V > = \int V_{eff}(r)|\psi(r)|^2d^3r \] \hspace{1cm} (10)

where, \( V_{eff}(r) = V_{Leff}(r) + V_{Ceff}(r) \) and \( \Psi(r) \) is the wave function of a typical nucleon. Thus the hamiltonian can be expressed as:

\[ < H > = < \frac{p^2}{2m} > + < V > \] \hspace{1cm} (11)

To estimate the energy we need the wave function for the nucleons. We have used the wave function for the nucleons suggested by the Statistical model [17]. The wave function in the ground state runs as[17],

\[ |\Psi(r)|^2 = \frac{315}{64\pi r_0^{9/2}}(r_0 - r)^{3/2}\theta(r_0 - r) \] \hspace{1cm} (12)

Where \( r_0 \) is the radius parameter of the corresponding hadron and \( \theta(r_0 - r) \) represents the step function. We have used this wave function for the nucleons.
may be mentioned that Mathieu et al [16] have used the Gaussian type of wave function for the nucleons in their investigation.

Considering proton as a five quark system with diquark-diquark-antiquark configuration as stated earlier, the Hamiltonian for the proton in reduced mass system is obtained as:

\[
<H_p> = \frac{29.678}{r_p^2} + 0.545(\sigma r_p) - 0.055(\sigma \rho r_p^4) - \frac{3\alpha_s}{r_p} + 0.312(\alpha_s \rho r_p^2) \tag{13}
\]

Similarly the Hamiltonian for the neutron in quark-diquark configuration has been estimated and is expressed as:

\[
<H_n> = \frac{26.366}{r_n^2} + 0.545(\sigma r_n) - 0.055(\sigma \rho r_n^4) - \frac{3\alpha_s}{r_n} + 0.312(\alpha_s \rho r_n^2) \tag{14}
\]

Minimizing the Hamiltonian in (13) and (14) with respect to the radius parameter we come across the following expressions:

\[
\frac{r_p}{r_p^0} = 1.259[1 + \sqrt{(1 - 175.73\rho)}]^{-1} \tag{15}
\]

\[
\frac{r_n}{r_n^0} = 1.260[1 + \sqrt{(1 - 156.618\rho)}]^{-1} \tag{16}
\]

Where \(r_p^0, r_n^0\) are the radius of the proton and the neutron respectively at \(\rho=0\), \(\rho\) is the density of the nuclear medium, \(r_p, r_n\) are the radius of proton and the neutron respectively in nuclear medium. The string tension \(\sigma\) is taken as 0.999\(GeV^2\) form [18]. \(GeV^2\). We have neglected the coulomb term to arrive at the expressions (15) and (16).

We have studied the variation of \(r/r^0\) with matter density \(\rho\) and it has been displayed in the Figure-1. The critical density is defined as the density at which the nucleon ceases to exist and in the present formulation it represents the density at which the radius of the nucleons in the nuclear medium becomes imaginary. We have estimated the the critical densities for the for proton and the neutron as 4.17 and 4.69 times the normal nuclear density respectively. The ratio of the masses of the nucleons in nuclear medium \(M^*\) to that of the free nucleon \(M_0\) have been estimated for both the proton and the neutron and have displayed in
For a bound nucleon the expression for the incompressibility runs as,

\[ K = \frac{1}{3} r^2 \frac{d^2 E}{dr^2} \quad (17) \]

We have estimated \( \Delta K \), the decrease in the incompressibility from free to normal nuclear medium for the proton and the neutron as 0.156 GeV and 0.132 GeV respectively. The variation of \( \frac{K}{K_0} \) with \( \rho \) have been shown in Figure-3 where \( K_0 \) is the incompressibility at \( \rho=0 \).

The expression for Roper excitation energy for a nucleon runs as:[16]

\[ \Delta E = \sqrt{\frac{K}{m r_0^2}} \quad (18) \]

We have obtained the values as 0.757 GeV and 0.699 GeV in the free space and in the normal nuclear density for the proton respectively whereas for the neutron the values are obtained as 0.728 GeV and 0.678 GeV respectively.

4. Structure Function and Gottfried Sum Rule

The study of the Structure function is important for the understanding of the quark structure of the nucleons. The free nucleon structure function in the non relativistic limit is expressed as [19]:

\[ F(x) = \frac{M}{8\pi^2} \int_{K_{\text{min}}}^{\infty} |\Psi(k)|^2 dk^2 \quad (19) \]

Where \( M \) is the mass of the nucleon and \( \Psi(k) \) is the normalized momentum space wave function and \( k_{\text{min}} = M |k - \frac{1}{3}| \). We have obtained the momentum space wave function \( \Psi(k) \) for the nucleon performing the Fourier transform of the wave function in (12). The momentum space wave function \( \Psi(k) \) is obtained as [20]:

\[ \Psi(k) = C_1 k^{-1} j_1(kr_0) \quad (20) \]

where \( C_1 \) is the normalization constant and obtained as \( 2\sqrt{3\pi r_0} \). We have estimated the structure function of the proton \( F_2^p \) and the neutron \( F_2^n \) with the input of \( \Psi(k) \) in equation (19) using \( r_p \) and \( r_n \) estimated from the equations (15) and (16). The variation of the ratio of the structure functions of the neutron to the proton with the density of the nuclear medium have been displayed in the Figure-4. The variation of the difference between the structure functions of the proton and the neutron with the density of the medium have been shown in the
The Gottfried Sum rule [21] $S_G$ can be expressed as,

$$S_G = \int_0^1 \frac{F_2^p(x) - F_2^n(x)}{x} dx = \frac{1}{3} \quad (21)$$

We have estimated $S_G = 0.173$ at $0 < x < 1$ for free nucleons. A violation is observed. We have investigated the variation of $S_G$ with $\rho$ and the variations is displayed in the Figure-6. Our result agrees well with the existing theoretical and experimental predictions. We have observed that the GT Sum increases with increasing medium density. It rises up to $3.5 \rho_0$ and then increases rapidly till the critical density.

5. Result and Discussion

In this Present work we have investigated the modifications of the properties of the proton and the neutron in the nuclear medium. The new thing in the current investigation is the inclusion of the strange quark-anti quark contributions to the configuration of the proton. We have computed the masses of the proton and the neutron considering diquark as a fundamental constituent. The quasi particle picture of the effective mass approximation for diquark suggested by us [11] has been employed. The properties like swelling, incompressibility, Roper resonance, structure function and Gottfried Sum rule of nucleons have been studied with the change of the nuclear matter density. The swelling of the proton and the neutron in the nuclear medium have been shown in the Figure-1. It has been observed that at the higher nuclear matter density swelling of the proton is more than the neutron which indicates the fact that the effect is more pronounced in the proton. We have observed 18 percent swelling in the proton radius at critical density $\rho_c$ whereas neutron shows 13 percent swelling. In the context of non topological model Wen et al [22] have obtained 10-16 percent swelling of the nucleon radius at the critical density. Noble et al [23] have estimated the increase in size as 30 percent whereas Mathieu et al [16] have observed 25 percent swelling for the nucleon. We have obtained critical density as $4.17\rho_0$ and $4.69\rho_0$ for the proton and the neutron respectively which indicates that the neutron survives more than the proton with respect to the nuclear medium. Mathieu [16]
et al [24] have estimated the critical density as $8\rho_0$ at which radius shows an infinite value indicating a phase transition. Figure-2 represents the variation of the masses with the nuclear density. It has been observed that the nuclear medium causes a decrease in the mass of the nucleon. We have observed a decrease of the masses of the proton form free to the normal nuclear density as 0.8 percent whereas 0.6 percent is observed for the neutron. The swelling of the proton is estimated as 2.15 percent whereas for the neutron 1.96 percent has been obtained at normal nuclear density $\rho_0$. Wen et al [22] have also investigated the variation of masses of the nucleons with medium density and have observed a decrease in mass. It is interesting to observe here that the effect of the nuclear medium is more pronounced in changing the size of the nucleon than the mass of the nucleons from free to normal nuclear medium. Similar observation is made by Wen et al [22]. Figure-3 represents the variation of the incompressibility in the nuclear medium. The decrease in K from free to normal nuclear medium are estimated as $\Delta K$ 0.156 GeV for the proton and 0.132 GeV for the neutron. Mathieu et al [16] have estimated the difference as 0.041 GeV. Meissner et al [25] have investigated the incompressibility of the nucleon and have obtained the value as 3GeV in the relativistic approach. It is known that the incompressibility is related to the excitation mode of the vibration and the Roper excitation energy can be estimated form the knowledge of the incompressibility. We have obtained the Roper resonance excitation energy as 0.757 GeV for free proton and 0.699 GeV for the proton at normal nuclear density whereas for the neutron we have obtained the values as 0.728 GeV and 0.678GeV respectively. The result shows that the resonance state is more tightly bound in nuclear medium than in the free nucleon. The current investigation yields comparatively larger value of the Roper resonance compared to the experimental value which is $\sim$ 500 MeV. Mathieu et al [16] have obtained the values as 0.345 and 0.330 GeV respectively whereas Meissner et al [25] have extracted it as 390 MeV. However it may be pointed out that the radius parameter of the nucleon $r_0$ is not exactly known and may shed some uncertainty in the results particularly to the excitation energy of the Roper resonance.

The structure function $F_2(x, Q^2)$ has been estimated and the variation with
have been used to compute $F_2(x)$. Using the radius $r_p, r_n$ from (15) and (16) we have evaluated the structure functions $F_n^p, F_p^n$ for $x \rightarrow 1$. Results show some interesting behavior regarding the ratio of structure functions and Gottfried Sum Rule in medium. Figure-4 shows a gradual decrease of the ratio of the structure functions of the neutron to the proton with increasing $\rho$ up to $3.5 \rho_0$ after which it falls sharply. The variation in the difference between the structure functions of the proton and the neutron i.e. $(F_p^p - F_p^n)$ have been displayed in the Figure-5. It shows an increasing behavior as the density of the nuclear medium increases. The variation of the Gottfried Sum Rule with the nuclear medium density has been studied and have displayed in Figure-6. We have found $S_G$ to be $0.173$ at $0 < x < 1$ for the free nucleon. Experimental prediction is $0.197\pm0.011(\text{st.})\pm0.083(\text{sys.})$ at $0.02 < x < 0.8$, $10 < Q^2 < 90 \text{ GeV}^2$ [26] whereas NMC predicts the value as $0.221\pm0.008(\text{st.})\pm0.019(\text{sys.})$ for $0.004 < x < 0.8$ at $Q^2 = 4 \text{ GeV}^2$ [27]. The result obtained in the current investigation are found to be in the range of the experimental predictions. Current investigation shows that the values of the Gottfried Sum rule increases with the increase of the medium density. It rises up to $3.5 \rho_0$ and then increases rapidly till the critical density. The variation of the nuclear structure functions in the nuclear medium have been studied by a number of authors [28]. Rozynek [5] has studied the modification of the nuclear structure function in nuclear matter above the saturation point in the relativistic mean field approach. They have pointed out that the density evolution seems to be stronger at the high densities. Cloet et al [29] have studied the spin dependent structure functions of the nucleons in the context of the modified NJL model. They have used the model to study the modification of $F_2$ structure functions in the nuclear medium and have suggested that the change the spin structure function of a bound nucleon in the nuclear matter is roughly twice as large as the change in the spin independent structure function. It may be mentioned that recently Osipenko et al [30] have reported the measurement of inclusive electron scattering from CLAS at JLab. They have evaluated the $F_2$ structure functions and the corresponding moments. They have speculated that special extension of nucleon changes in the nuclear matter from the study of the structure function ratio of carbon to deuteron.
diquark-diquark-antiquark scheme incorporating the strange contribution. This enable us to distinguish between the proton and the neutron via their quark configurations. Consequently their properties are distinguishable and show a difference. The current approach is a naive one where the radius of the relevant nucleon is the only parameter for estimating the properties. The configurations of the proton and the neutrons with diquark approach reproduce the results which are in reasonably good agreement with other works. It may be mentioned that Trevisan et al [31] have studied the structure function of a nucleon in a statistical model incorporating strangeness content of proton. They have studied the violation of the Gottfried sum rule and have observed that NMC [27] results are well reproduced in this approach.

The study of the structure functions and the violation of Gottfried sum rule provides important information regarding the structure of the nucleons. It has been suggested that the violation occurs due to the extrinsic contribution from the gluon chains which are splitted into quark-antiquark pairs producing a sea quark asymmetry. In the current work it has been suggested that the 'intrinsi-c' sea has significant contribution and reproduces the results well. Recently Chang et al[32] have investigated the intrinsic charm quark contribution to proton via uudc\overline{c} configuration and investigated the five quark Fock states. They have also investigated the light pentaquark quark Fock states of the proton and have pointed out that the 'intrinsic' charm production is valance like with distribution peaking at large x whereas extrinsic production is 'sea' like with significant contribution at small x. Results obtained are very interesting and agrees with other available estimates. We have observed that the violation increases with the density of the medium indicating the fact that the quark density affects the virtual quark sea of the proton and the neutron. In the present investigation the effect is probed through the swelling of the nucleon in medium. Studying the effect of the medium on the modification of the properties of the nucleons are very important. It throws some light on the quark structure of the nucleons and their dynamics as the constituent quarks are attracted by the neighbouring nucleons. We have tried to incorporate $s\overline{s}$ effect in proton in current work. It may be mentioned that the contribution due to strange quarks sea has been incorporated as
than 15 to 20 percent to the magnetic moment. However it may be mentioned that there is a number of works [33-34] where the strange contribution has been treated as valence contribution and the proton is described as a penta quark system particularly to study the magnetic moments of the proton. It is pertinent to point out here that the proton is a complicated object with the contributions from the valance quarks, the gluons and the strange quark sea. It is a challenging job to reveal the proton structure. Only 50 percent of the proton momentum is carried by the valence quarks [33]. It has also been suggested that 30 percent of the proton spin is carried by strange sea. The current experimental results hints to the fact that the proton flavour structure may not be limited to u and d only. Probing the structure of the proton is a challenging job to the modern day particle physics. It is interesting to study the effect of the strange contribution to the properties of the proton. We have incorporated the strange pair contribution to the proton configuration as five quark system and have investigated the possibility whether the sea quark asymmetry between the two nucleons can be attributed to the strange sea quark contribution to the proton flavour structure. It may be asserted that the quark structure and the medium play an important role in modifying the properties of the nucleons. More investigations on the the structure of the proton and its resonance states in medium with vector diquark would be studied in our future works.

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Figure Captions:

Fig. 1. The ratio of the nucleon radius in nuclear matter to that in free space ($r/r^0$) as a function of nuclear matter density ($\rho$).

Fig. 2. The ratio of the nucleon mass in nuclear matter to that in free space ($M^*/M$) as a function of nuclear matter density ($\rho$).

Fig. 3. The ratio of Incompressibility of nucleon in nuclear matter to that in free space ($K/K_0$) as a function of nuclear matter density ($\rho$).

Fig. 4. The ratio of the structure function of neutron to that of proton as a function of nuclear matter density ($\rho$).

Fig. 5. The difference between the Structure function of proton and neutron as a function of nuclear matter density ($\rho$).

Fig. 6. The variation of GT Sum Rule as a function of nuclear matter density ($\rho$).