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Intrinsic Confinement Pressure and Saturation Density of Nucleon Matter: Emergence of Natural Scales ($\sim 10^{34}$ N/m², $\sim 10^{17}$ kg/m³)

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Abstract

This work presents a unified scaling framework for nucleon matter, demonstrating that its characteristic saturation density and intrinsic confinement pressure emerge naturally from a minimal set of physical considerations anchored in the neutron mass. A classical confinement model based on internal charge interaction yields a pressure scale of the order of 10^{34} N/m² and a corresponding density of the order of 10^{17} kg/m³ at nucleon length scales. Independently, a quantum–relativistic scaling approach leads to the same characteristic values when the neutron mass is treated as the fundamental scale-setting parameter. An additional electromagnetic scaling formulation further reproduces the same confinement pressure when evaluated at femtometer scales. The convergence of these independent approaches indicates that these values represent intrinsic properties of nucleon matter rather than model-dependent results. The analysis shows that once the neutron mass is fixed, the nucleon radius, saturation density, and confinement pressure follow self-consistently, without requiring external assumptions. These findings highlight the emergence of natural scales in nuclear matter and provide a simplified physical interpretation of known nuclear density and pressure regimes.

Keywords: Nucleon matter, Nuclear saturation density, Intrinsic confinement pressure, Neutron mass scaling, Energy density, Nuclear matter equation of state, Quantum–relativistic scaling Coulomb confinement, Nuclear length scale, Black Hole

1. Introduction

The determination of characteristic density and pressure scales in nuclear matter remains a central problem in modern physics. While the saturation density of nuclear matter is well established experimentally at approximately 10^{17}–10^{18} kg/m³, its physical origin is typically described within complex many-body frameworks and phenomenological models [1–3]. Similarly, the corresponding pressure scales relevant to nucleon confinement and neutron star interiors are obtained through equation-of-state formulations that rely on fitted interaction potentials and numerical simulations [4–6].

In conventional approaches, the structure of nuclear matter is interpreted through quantum chromodynamics (QCD), where nucleons emerge as bound states of quarks and gluons. Although QCD successfully explains a wide range of high-energy phenomena, the direct derivation of bulk properties such as saturation density and confinement pressure from first principles remains analytically intractable and is generally addressed through lattice computations and effective theories [7–9]. As a result, the fundamental origin of the characteristic nuclear scales is often obscured by computational complexity.

An alternative viewpoint is to examine whether these scales can emerge from simpler and more transparent physical considerations. In particular, the neutron—being a ubiquitous and structurally stable constituent of nuclear matter—provides a natural reference scale. Its mass, energy, and characteristic length are well defined experimentally and are common to all nuclear systems. This raises a fundamental question: whether the observed saturation density and confinement pressure of nucleon matter can be obtained directly from a minimal set of physical inputs anchored in the neutron scale.

Recent work by the present authors has explored classical charge-based models of neutron structure, demonstrating that confinement forces and pressure scales can arise from internally confined charge configurations without invoking full quantum field formulations [11,12]. A broader framework relating elementary charge–energy units to matter evolution has also been proposed, offering an alternative perspective on energy scaling in physical systems [13]. In addition, a pressure-based stability criterion for self-gravitating matter has been developed, emphasizing the role of intrinsic pressure scales in determining structural equilibrium [14]. Further, a radius-based study of neutron-cored black hole configurations has shown that matter densities of the order of 10^{17} kg/m³ naturally emerge in extreme gravitational systems, indicating that this density scale may persist across both nuclear and astrophysical regimes [15].

Previous studies have identified the existence of a nearly constant nuclear saturation density and have related it to short-range interactions between nucleons [1,3]. Likewise, the concept of pressure arising from confined energy density is well understood in both classical and relativistic contexts [4,10]. However, a unified scaling framework that connects neutron properties directly to the simultaneous emergence of both density and pressure scales remains largely unexplored.

In this work, we develop a simple and self-consistent scaling framework in which the neutron mass is treated as the primary scale-setting parameter. Starting from a classical confinement model based on internal charge interactions, we obtain a characteristic pressure of the order of 10^{34} N/m² and a corresponding density of the order of 10^{17} kg/m³ at nucleon length scales. Independently, a quantum–relativistic scaling argument leads to the same characteristic values without additional assumptions. An electromagnetic scaling formulation further reproduces the same pressure scale when evaluated at femtometer confinement lengths.

The convergence of these independent approaches suggests that the saturation density and intrinsic confinement pressure of nucleon matter are not model-dependent quantities, but rather natural scales emerging from fundamental physical constraints. The analysis provides a transparent physical interpretation of these scales and highlights the role of the neutron as a natural anchor for matter.

Although the present estimates of confinement pressure and density are obtained within the framework of the neutron model, it is noteworthy that values of similar order—namely, pressures around 10^{34} N/m² and densities near 10^{17} kg/m³,appear independently across a range of nuclear and astrophysical studies.

These include descriptions of nuclear saturation, neutron star interiors, and dense matter equations of state. The recurrence of these scales in otherwise distinct physical contexts suggests that they may not be merely model-specific outcomes, but rather reflect a common underlying constraint associated with strongly confined matter. The present work does not claim universality of these values across all systems; however, the consistent emergence of comparable magnitudes indicates the possibility of a deeper connection between confinement, density, and energy scales in nucleon-based matter.

2. Main Framework: Characteristic Confinement Frame Work

2.1 Confinement Definition

We consider a system in which energy (E) is confined within a characteristic length scale (R). The corresponding energy density (u) is:

$$u = \frac{E}{R^3} \tag{1}$$

This defines the **confinement energy density** of the system.

2.2 Construction of the Qc Energy Scale:

We construct a characteristic energy scale using experimentally observed nuclear energies [11,12].
Beta decay energy:

$$E_{beta} \approx 1.293\ MeV \tag{2}$$

Deuteron binding energy:

$$E_b \approx 2.224\ MeV \tag{3}$$

Thus, the characteristic energy per Qc unit is:

$$E_{qc} = E_{beta} + E_b \approx 3.46\ MeV \tag{4}$$

This represents a composite scale combining:

- decay (charge separation)
- binding (nuclear cohesion)

2.3 Estimation of Number of Qc Units

Total neutron energy:

$$E_n \approx 939.565\ MeV \tag{5}$$

Assuming:

$$E_n = D_{qc} * E_{qc} \tag{6}$$

$Then$:

$$D_{qc} = \frac{E_n}{E_{qc}} \approx \frac{939.565}{3.46} \approx 271 \quad (7)$$

This convergence supports the existence of a discrete internal confinement structure.

2.4 Neutron Radius and Qc Scale:

Effective neutron radius:

$$R_n \approx 1.0 * 10^{-15} m \quad (8)$$

Free neutron radius:

$$R_o \approx 1.23\, x\, 10^{-15} m \quad (9)$$

Assuming volumetric packing:

$$R_{qc} = \frac{R_n}{(D_{qc})^{\frac{1}{3}}} \quad (10)$$

Numerically:

$$R_{qc} \approx 0.155\, x\, 10^{-15} m \quad (11)$$

2.5 Coulomb Confinement Force at Qc Level:

$$F_{qc} = \frac{q^2}{(4\pi\, \varepsilon_0\, R_{qc}^2)} \quad (12)$$

Substituting:

$$F_{qc} \approx 9.6\, x\, 10^3\ N \quad (13)$$

2.6 Intrinsic Surface Confinement Pressure of Nucleon matter (P_s):

$$A_{qc} = 4\,\pi\, R_{qc}^2 \quad (14)$$

Pressure:

$$P_s = \frac{F_{qc}}{A_{qc}} \quad (15)$$

Thus:

$$P_s = \frac{q^2}{(16\,\pi^2\,\varepsilon_0\,R_{qc}^4)} \tag{16}$$

Numerically:

$$P_s \approx 3.2\,x\,10^{34}\,N/m^2 \tag{17}$$

This represents the **Intrinsic Confinement Pressure of Nucleon Matter**.

2.7 Density and Energy Density:

Mass per Qc unit:

$$m_{qc} = \frac{m_n}{D_{qc}} \approx 6.18\,x\,10^{-30} kg \tag{18}$$

Saturation Density of Nucleon Matter (ρ_s):

$$\rho_s = \frac{m_{qc}}{\left(\left(\frac{4}{3}\right)\pi\,R_n^3\right)} \tag{19}$$

Numerically:

$$\rho_s \approx 3.96\,x\,10^{17}\,kg/m^3 \tag{20}$$

Energy density:

$$u = \rho_s\,x\,c^2 \tag{21}$$

$$u \approx 3.56\,x\,10^{34}\,J/m^3 \tag{22}$$

3. Neutron-Level Consistency:

Neutron parameters:

$F_n \approx 4\,x\,10^5\,N\,(newton)$
$R_n \approx 1.0\,x\,10^{-15} m$
$m_n \approx 1.68\,x\,10^{-27} kg$

Surface pressure:

$$P_s = \frac{F_n}{(4\,\pi\,R_n^2)} \tag{23}$$

$$P_s \approx 3.18\, x\, 10^{34}\, N/m^2 \tag{24}$$

Saturation Density of Nucleon Matter (ρ_s)

$$\rho_s = \frac{m_n}{\left(\left(\frac{4}{3}\right) \pi\, R_n^3\right)} \tag{25}$$

$$\rho_s \approx 3.96\, x\, 10^{17} kg/m^3 \tag{26}$$

Energy density:

$$u = \rho_s\ x\ c^2 \approx 10^{34} J/m^3 \tag{27}$$

4. Pressure–Energy Equivalence:
Since:

$$1\ \mathrm{J/m^3} = 1\mathrm{N/m^2} \tag{28}$$

We obtain:

$$P_s \approx u \tag{29}$$

Interpretation:

- (u) → fundamental energy density
- (P_s) → mechanical manifestation

5. Electromagnetic Scaling Consistency:
The characteristic confinement scale may also be examined using a purely electromagnetic formulation. From Coulomb interaction, the energy associated with a charge separation at scale R is:

$$E \approx \frac{q^2}{(4\, \pi\, \varepsilon_0\ R)} \tag{30}$$

Assuming this energy is confined within a volume of order R3R^3R3, the corresponding energy density becomes:

$$u \approx \frac{E}{R^3} \tag{31}$$

Substituting Eq. (30):

$$u \approx \frac{q^2}{(4\,\pi\,\varepsilon_0\ R^4)} \tag{32}$$

At R ≈ nucleon scale → u ≈ 10^{34} → therefore $P_s \approx\ \approx 10^{34}$

5.1 Interpretation:

This relation shows that energy density scales strongly with spatial confinement:

$$u \propto 1\,/\,R^4$$

Thus, even moderate reduction in confinement length produces a rapid increase in energy density.

5.2 Result at Nucleon Scale:

For:

$$R \approx 0.15\,fm$$

we obtain:

$$u \approx 10^{34} J/m^3$$

Using:

$$P_s \approx u$$

we obtain:

$$P_s \approx 10^{34} N/m^2$$

5.3 Significance:

This demonstrates that:

The intrinsic confinement pressure P_s and saturation density ρ_s emerge naturally from electromagnetic scaling at the nucleon length scale.

6. Quantum–Relativistic Consistency:

Using quantum–relativistic scaling, the characteristic length scale associated with the neutron is:

$$R \approx \frac{\hbar}{(m_n\ c)} \tag{33}$$

The corresponding density is: $\rho_s \ \hbar$

$$\rho_s \quad \approx \frac{m_n}{R^3} \tag{34}$$

Substituting for R:

$$\rho_s \quad \approx \frac{(m_n^4 \ c^3)}{\hbar^3} \tag{35}$$

The energy density is:

$$u \ \approx \ \rho_s \ \ x \ \ c^2 \tag{36}$$

Thus:

$$u \ \approx \frac{(m_n^4 \ c^3)}{\hbar^3} \ \ \mathrm{c}^2 = \frac{(m_n^4 * c^5)}{\hbar^3} \tag{37}$$

6.1 Results

At neutron scale: Saturation density: $\rho s \approx 10^{17}$ kg/m^3

Intrinsic confinement pressure: $Ps \approx 10^{34}$ N/m^2

6.2 Consistency

These values are in close agreement with those obtained from:

- classical confinement model
- electromagnetic scaling formulation

This confirms that the saturation density and confinement pressure emerge naturally from quantum–relativistic considerations.

7. Convergence of Natural Scales:

Two independent approaches:

As per Classical (Qc model) : $\rho_s \approx 10^{17}$, $\mathrm{P_s} \approx 10^{34}$
As per Quantum–relativistic : $\rho_s \approx 10^{17}$, $\mathrm{P_s} \approx 10^{34}$

The saturation density (~10^{17} kg/m^3) and intrinsic confinement pressure (~10^{34} N/m^2) of nucleon matter emerge as **natural scales**, consistently obtained from both classical confinement and quantum–relativistic scaling.

Conclusion:

The present work demonstrates that the characteristic properties of nucleon matter—namely its saturation density and intrinsic confinement pressure, emerge naturally from a simple and consistent scaling framework anchored in the neutron mass.

Using a classical confinement approach based on internal charge interactions, a characteristic pressure of the order of 10^{34} N/m² and a density of the order of 10^{17} kg/m³ are obtained at a length scale corresponding to the nucleon radius. These values arise without the need for externally imposed assumptions, but rather from the internal balance of forces within the system.

Independently, a quantum–relativistic scaling approach leads to the same characteristic density and pressure scales when the neutron mass is taken as the fundamental parameter. This agreement between two distinct approaches, classical confinement and quantum scaling, indicates that these values are not coincidental, but represent intrinsic properties of nucleon matter.

Further, an electromagnetic scaling perspective shows that when charge interactions are confined to nucleon-length scales, the same pressure scale naturally appears. This provides an additional level of consistency and reinforces the universality of the result.

The analysis establishes that the neutron mass acts as a natural scale-setting parameter for matter. Once this scale is fixed, the nucleon radius, saturation density, and confinement pressure follow in a self-consistent manner. No independent assumptions regarding density or pressure are required.

The saturation density (~10^{17} kg/m³) and intrinsic confinement pressure (~10^{34} N/m² are natural scales of nucleon matter, emerging consistently from independent classical, electromagnetic, and quantum–relativistic considerations. Fix the neutron, and the natural scales of matter emerge.

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