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On the Possible Role of the Planck Length in Fitting the Neutron Lifetime

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Abstract

At present, no unified formula is available for estimating the Planck length or the Newtonian gravitational constant in terms of elementary physical constants. In this context, considering our 4G model of final unification, we have noticed a simple relation for fitting the Planck length in terms of nuclear physical constants. The hypothetical distance travelled by photon in a time span equal to the neutron lifetime seems to be: 1) Directly proportional to the proton mass and the nuclear volume; 2) Inversely proportional to the nucleon mass difference, 4G model of weak interaction range and twice the Planck length. It may be noted that, twice the Planck length can be understood as the Schwarzschild radius of the Planck mass. This relation seems to highlight the need and accuracy of the nuclear charge radius and neutron lifetime. Considering our 4G model, nuclear charge radius is 1.2393 fermi and fitted neutron lifetime is 884.2 sec. For a nuclear radius of (1.23 to 1.24) fermi, obtained neutron life time is (864.5 to 885.7) sec. Interesting point to be noted is that, a small reduction in nuclear volume seems to reduce the neutron lifetime significantly. We are working on understanding the reasons in terms of weak interaction and difference in sub-zero cooling temperatures of the bottle and beam methods of neutron lifetime experiments. Proceeding further, without considering any arbitrary coefficients or numbers, the most complicated macroscopic Newtonian gravitational constant can be estimated in a semi empirical approach connected with neutron lifetime experiments and nuclear charge radii experiments.

Keywords: Planck length; neutron decay & lifetime; nuclear charge radius; 4G model of final unification; weak fermion of rest energy 584.725 GeV; 4G model of weak interaction range; big G

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1. Introduction

The quest to unify gravity with the quantum realm continues to be the centre piece of modern theoretical physics [1]. Despite the success of quantum field theories in describing electromagnetic, weak, and strong interactions, gravity has resisted integration into this framework. Most unification attempts invoke extrapolated scales or speculative frameworks-string theory [2], loop quantum gravity [3], or higher-dimensional models-yet lack empirical pathways connecting measurable constants to Planck-scale quantities. In this context, we explore the possibility that Planck-scale physics-specifically, the Planck length [4] and the Newton's gravitational constant-may find expression not in the remote energy domains but through the structure of nuclear matter and decay phenomena. In the following section, we introduce the assumptions and simple applications of our 4G model of final unification [5–12]. Readers are encouraged to refer our recent papers for a better understanding [5,6].

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2. Three Assumptions of 4G Model of Final Unification and Simple Applications

Following our 4G model of final unification [5–12]

1) There exists a characteristic electroweak fermion of rest energy, $M_{wf}c^2 \cong 584.725 \text{ GeV}$. It can be considered as the zygote of all elementary particles.
2) There exists a nuclear elementary charge in such a way that, $\left(\frac{e}{e_n}\right)^2 \cong \alpha_s \cong 0.1152$ = Strong coupling constant and $e_n \cong 2.9464e$.
3) Each atomic interaction is associated with a characteristic large gravitational coupling constant. Their fitted magnitudes are,

$$G_e \cong \text{Electromgnetic gravitational constant} \cong 2.374335 \times 10^{37} \ \text{m}^3\text{kg}^{-1}\text{sec}^{-2}$$
$$G_n \cong \text{Nuclear gravitational constant} \cong 3.329561 \times 10^{28} \ \text{m}^3\text{kg}^{-1}\text{sec}^{-2}$$
$$G_w \cong \text{Electroweak gravitational constant} \cong 2.909745 \times 10^{22} \ \text{m}^3\text{kg}^{-1}\text{sec}^{-2}$$

It may be noted that,

1) Weak interaction point of view [13,14], following our assumptions, Fermi's weak coupling constant can be fitted with the following relations.

$$\left.\begin{array}{l} G_F \cong \left(\frac{m_e}{m_p}\right)^2 \hbar c R_0^2 \cong G_w M_{wf}^2 R_w^2 \ \cong 1.44021 \times 10^{-62} \ \text{J.m}^3 \\ \text{where,} \left\{\begin{array}{l} R_0 \cong \frac{2G_n m_p}{c^2} \cong 1.24 \ \times 10^{-15} \ \text{m} \\ R_w \cong \frac{2G_w M_{wf}}{c^2} \cong 6.75 \times 10^{-19} \ \text{m} \end{array}\right. \end{array}\right\} \quad (1)$$

2) In a unified approach, most important point to be noted is that,

$$\hbar c \equiv G_w M_{wf}^2 \quad (2)$$

Clearly speaking, based on the electroweak interaction, the well believed quantum constant $\hbar c$ seems to have a deep inner meaning. It needs further study with reference to EPR argument [1,10]. String theory [2,3] can be made practical with reference to the three atomic gravitational constants associated with weak, strong and electromagnetic interaction gravitational constants. See Table 1. and Table 2. for sample string tensions and energies without any coupling constants.

Table 1. Charge dependent string tensions and string energies.

S.No	Interaction	String Tension	String energy
1	Weak	$\frac{c^4}{4G_w} \cong 6.94 \times 10^{10} \ \text{N}$	$\sqrt{\frac{e^2}{4\pi\varepsilon_0}\left(\frac{c^4}{4G_w}\right)} \cong 24.975 \text{ GeV}$
2	Strong	$\frac{c^4}{4G_n} \cong 6.065 \times 10^4 \ \text{N}$	$\sqrt{\frac{e_n^2}{4\pi\varepsilon_0}\left(\frac{c^4}{4G_n}\right)} \cong 68.79 \text{ MeV}$
3	Electromagnetic	$\frac{c^4}{4G_e} \cong 8.505 \times 10^{-5} \ \text{N}$	$\sqrt{\frac{e^2}{4\pi\varepsilon_0}\left(\frac{c^4}{4G_e}\right)} \cong 874.3 \text{ eV}$

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Table 2. Quantum string tensions and string energies.

S.No	Interaction	String Tension	String energy
1	Weak	$\frac{c^4}{4G_w} \cong 6.94\times10^{10}\ \text{N}$	$\sqrt{\hbar c\left(\frac{c^4}{4G_w}\right)} \cong 292.36\ \text{GeV}$
2	Strong	$\frac{c^4}{4G_n} \cong 6.065\times10^{4}\ \text{N}$	$\sqrt{\hbar c\left(\frac{c^4}{4G_n}\right)} \cong 273.3\ \text{MeV}$
3	Electromagnetic	$\frac{c^4}{4G_e} \cong 8.505\times10^{-5}\ \text{N}$	$\sqrt{\hbar c\left(\frac{c^4}{4G_e}\right)} \cong 10234.77\ \text{eV}$

3) Newtonian gravitational constant can be expressed as [15,16],

$$G_N \cong \frac{G_w^{21}G_e^{10}}{G_n^{30}} \cong 6.679851\times10^{-11}\text{m}^3\text{kg}^{-1}\text{sec}^{-2} \tag{3}$$

4) Strong coupling constant can be expressed as [17],

$$\alpha_s \cong \frac{G_w^{6}G_e^{4}}{G_n^{10}} \cong 0.115193455 \tag{4}$$

5) Avogadro like large number can be expressed as [18],

$$\begin{aligned} X &\cong \frac{\text{Product of short range gravitational constants}}{\text{Product of long range gravitational constants}} \\ &\cong \frac{G_n G_w}{G_N G_e} \cong 6.1088144\times10^{23} \end{aligned} \tag{5}$$

3. Photon Transit over Neutron Lifetime: An Assumed Fundamental Construct

Consider a photon traveling a distance $S_{tn} \cong ct_n$, where t_n is the free neutron lifetime. We hypothesize that this macroscopic-seeming length can be re-expressed through a combination of nuclear-scale quantities:

$$S_{tn} \cong \left[\frac{m_p}{(m_n - m_p)}\right]\frac{V_0}{R_{pl}R_w} \cong \left[\frac{m_p}{(m_n - m_p)}\right]\frac{4\pi R_0^3}{3R_{pl}R_w} \tag{6}$$

Here,

$S_{tn} \cong ct_n$ =Distance travelled by photon in the lifetime of neutron t_n.

$m_p \cong 938.272\ \text{MeV}/c^2$ = Proton rest mass

$m_n \cong 939.5654\ \text{MeV}/c^2$ =Neutron rest mass

$G_n \cong 3.329561\times10^{28}\ \text{m}^3\text{kg}^{-1}\text{sec}^{-2}$ = Nuclear gravitational constant

R_0 =Nuclear charge radius = $\frac{2G_n m_p}{c^2}$ =1.23929 fermi

V_0 = Nuclear volume corresponding to R_0

G_N = Newtonian gravitational constant

$R_{pl} = \frac{2G_N M_{pl}}{c^2} \cong 2\sqrt{\frac{G_N \hbar}{c^3}}$ = Schwarzschild radius of the Planck mass, $M_{pl} \cong \sqrt{\frac{\hbar c}{G_N}}$

G_F =Fermi's weak coupling constant.

R_w =Weak interaction range = $\frac{2G_w M_{wf}}{c^2} \cong \sqrt{\frac{G_F}{\hbar c}} \cong 6.75\times10^{-19}$ m

$G_w \cong 2.909745\times10^{22}\ \text{m}^3\text{kg}^{-1}\text{sec}^{-2}$ = Weak gravitational constant

$M_{wf} \cong 584725\ \text{MeV}/c^2$ = Rest mass of Electroweak fermion

Based on this relation, Planck length can be expressed as,

$$\sqrt{\frac{G_N \hbar}{c^3}} \cong \left[\frac{m_p}{(m_n - m_p)}\right]\frac{2\pi R_0^3}{3R_w c t_n} \tag{7}$$

$$t_n \cong \left[\frac{m_p}{(m_n - m_p)}\right]\frac{2\pi R_0^3}{3R_w}\sqrt{\frac{c}{\hbar G_N}} \cong 884.245\ \text{sec} \tag{8}$$

where $G_N \cong 6.6743\times10^{-11}\text{m}^3\text{kg}^{-1}\text{sec}^{-2}$

Newtonian gravitational constant can be expressed as

$$G_N \cong \left[\frac{m_p}{(m_n - m_p)}\right]^2 \frac{4\pi^2 R_0^6 c}{9R_w^2 t_n^2 \hbar} \tag{9}$$

$$\hbar G_N \cong \left[\frac{m_p}{(m_n - m_p)}\right]^2 \frac{4\pi^2 R_0^6 c}{9R_w^2 t_n^2} \tag{10}$$

4. Neutron Lifetime Dependence on Nuclear Charge Radius

Based on relation (8), it is possible to show that,

$$t_n \propto \frac{R_0^3}{R_w} \tag{11}$$

What is particularly striking is the sensitivity of neutron lifetime to small variations in the nuclear volume. It may be noticed that 0.01 fm reduction in nuclear charge radius can lead to noticeable changes in the neutron lifetime [21–25]. For example, considering a nuclear charge radius of $R_0 \cong (1.23\text{ to }1.24)$ fm, obtained $t_n \cong (875.2 \mp 10.6)$sec. It seems that, there exists an unknown interaction between neutron decay phenomenon, nuclear volume and the Planck scale. It needs further study.

Interesting point to be noted is that, Planck scale [26,27] seems to be a kind of reference scale for the elementary particles independent of the generally believed concept of 'higher energy limit'. Proceeding further, Planck scale can also be viewed as 'a hidden and unknown component of quantum gravity' linked with nuclear and atomic structures.

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5. Beam–Bottle Methods and the Thermodynamic Context

Experimental discrepancies in neutron lifetime measurements using beam and bottle methods [21–25] offer a natural testing ground for this framework. The beam method typically results in lifetime of 885 seconds, while the bottle approach reports a lifetime of 878 seconds. We propose that this divergence reflects subtle thermodynamic influences:

a) The bottle method, involving ultracold environments and magnetic confinement, may influence quantum tunneling and energy levels of neutron decay.
b) The beam method, operating under different vacuum and interaction conditions, may alter decay probabilities.

In this light, neutron decay ceases to be an immutable constant and instead becomes a thermodynamic variable, contingent on environmental factors such as energy distribution, boundary conditions, and quantum state configuration.

6. Newton's Gravitational Constant from Nuclear Metrics

Based on relation (9), Newtonian gravitational constant [15,16,28] can be expressed as,

$$G_N \propto \left(\frac{R_0^6}{t_n^2 R_w^2} \right) \tag{12}$$

In a unified approach, this relation seems to show a path for estimating the currently believed 'big G' in a semi empirical approach connected with nuclear physical constants. Here it seems important to highlight our two observed or defined relations for understanding the relationship between the nuclear scale and the Planck scale [6].

$$\frac{R_0}{R_{pl}} \cong \frac{G_n m_p}{G_N M_{pl}} \cong \frac{G_n m_p}{\sqrt{\hbar c G_N}} \cong \left(\frac{m_p}{m_e} \right)^6 \cong (\text{'Proton and Electron' mass ratio})^6 \tag{13}$$

$$\frac{G_w}{G_N} \cong \left(\frac{m_p}{m_e} \right)^{10} \cong (\text{'Proton and Electron' mass ratio})^{10} \tag{14}$$

These two relations will certainly help in exploring the secrets of microscopic quantum gravity.

7. Connecting the Newton's Gravitational Constant and the Fermi's Weak Coupling Constant

Considering the 4G model of our weak interaction range, Newtonian gravitational constant and the Fermi's weak coupling constant can be related in the following way. Writing our 4G model of weak interaction range as, $R_w \cong \frac{2G_w M_{wf}}{c^2} \cong \sqrt{\frac{G_F}{\hbar c}}$, Planck length can be expressed as shown.

$$\sqrt{\frac{G_N \hbar}{c^3}} \cong \left[\frac{m_p}{(m_n - m_p)} \right] \frac{2\pi R_0^3}{3ct_n} \sqrt{\frac{\hbar c}{G_F}} \tag{15}$$

Thus,

$$G_F \cong \left[\frac{m_p}{(m_n - m_p)}\right]^2 \frac{4\pi^2 R_0^6 c^2}{9t_n^2 G_N} \tag{16}$$

$$G_N \cong \left[\frac{m_p}{(m_n - m_p)}\right]^2 \frac{4\pi^2 R_0^6 c^2}{9t_n^2 G_F} \tag{17}$$

$$t_n \cong \left[\frac{m_p}{(m_n - m_p)}\right] \frac{2\pi R_0^3 c}{3\sqrt{G_F G_N}} \cong \left[\frac{m_p}{(m_n - m_p)}\right] \frac{V_0 c}{2\sqrt{G_F G_N}} \tag{18A}$$

$$ct_n \cong \left[\frac{m_p}{(m_n - m_p)}\right] \frac{2\pi R_0^3 c^2}{3\sqrt{G_F G_N}} \cong \left[\frac{m_p}{(m_n - m_p)}\right] \frac{V_0 c^2}{2\sqrt{G_F G_N}} \tag{18B}$$

8. Implications and Outlook

The implications of this work are two-fold:

1) Microphysical origins of gravity: Gravity may arise not from spacetime curvature alone, but from residual effects of nuclear configuration, decay lifetimes, and quantized space within the nucleons.
2) Experimental pathways to unified physics: Rather than extrapolating from unreachable high-energy domains, future unification models may lean more heavily on precision nuclear physics, specifically:
   a) Improved measurements of neutron lifetime under varying thermodynamic conditions
   b) High-resolution mapping of nuclear charge distributions
   c) Cross-analysis of weak interaction phenomenology and vacuum energy considerations

9. Conclusion

In this paper, independent of arbitrary coefficients or numbers, we have shown simple empirical relations for connecting the Planck length and neutron lifetime via nuclear physical constants. In view of the proposed relation (1), relation (6) can be considered as a supporting and validating application for our 4G model of 'weak interaction range'. Proposed relations (1) to (18) can be recommended for further research in view of understanding the potential applications of Planck scale as a reference scale linked with unknown aspects of microscopic quantum gravity on low energy scales. Proceeding further, Newtonian gravitational constant (big 'G') can be estimated in a hybrid mode associated with elementary nuclear physical constants like nucleon rest masses, electron rest mass, nuclear charge radii and the neutron lifetime.

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