# Emergence of Nuclear Structure from Time-Scalar Field Theory

Jordan G. Farrell[1]

[1]Independent Researcher, Time-Scalar Field Theory, ORCID: 0009-0002-2171-809X, The Zebra Journal of Unified Physics (ZJUP)

**Abstract**

We derive the emergence of nuclear-like composite structure from Time-Scalar Field Theory (TSFT), in which time is promoted to a physical scalar field $\Theta(x,t)$ and matter arises from coherence-stable eigenmodes of the scalar-time operator. Building on the previously derived particle spectrum, closure condition, and interaction hierarchy, we show that confined multi-fermion bound states arise naturally from composite coherence locking without introducing new fundamental postulates.

Starting from the scalar-time field, the coherence eigenvalue problem, and the closure condition

$$3n + 2q + h \equiv 0 \pmod 6,$$

we construct admissible three-fermion composite states and derive the conditions under which integer-charged spin-$\frac{1}{2}$ nucleon-like structures emerge. In particular, we show that the minimal closure-preserving confined composites built from admissible fractional-charge fermionic modes yield a positively charged proton-like state and a neutral neutron-like state as the first nontrivial nuclear-scale bound structures of the theory.

We further show that mass-energy equivalence is recovered directly from scalar-time eigenfrequency structure, without invoking General Relativity, through the identification of rest mass as the intrinsic coherence frequency of a stable mode. This yields the relativistic rest-energy relation

$$E = mc^2$$

as a consequence of scalar-time wave dynamics and provides the natural energetic framework for composite nuclear binding.

The resulting formalism supplies a self-contained derivation of nucleon-like bound states, composite confinement, and the first layer of nuclear structure directly from scalar-time coherence dynamics. This extends TSFT from particle and interaction emergence into the nuclear domain and provides a structural bridge from temporal resonance to matter architecture.

## 1. Introduction

Time-Scalar Field Theory (TSFT) begins from the postulate that time is not a passive coordinate but a physical scalar field:

$$\Theta(x,t). \tag{1}$$

In this framework, physical structure arises from gradients, curvature, phase closure, and coherence stability within the scalar-time field. Stable matter states are not assumed as primitive objects. Rather, they appear as persistent coherence-preserving eigenmodes of scalar-time dynamics.

Earlier stages of the TSFT program established the central particle and interaction spine of the framework. First, admissible particle-like states were derived from the scalar-time coherence operator through the eigenvalue problem

$$\mathcal{C}_\Theta \psi_n = \lambda_n \psi_n, \tag{2}$$

with each admissible mode labeled by a discrete set of indices

$$\psi_{n,q,h,s}, \tag{3}$$

where $n$ denotes spectral level, $q$ family index, $h$ closure index, and $s$ spin. These modes satisfy the scalar-time closure condition

$$3n + 2q + h \equiv 0 \pmod 6, \tag{4}$$

which determines the admissible particle spectrum and produces the observed charge classes through

$$Q = \frac{h}{3}. \tag{5}$$

Second, the interaction structure of TSFT was derived from temporal-frame deformation. Writing the temporal gradient as

$$\tau_\mu = \partial_\mu \Theta + a_\mu, \tag{6}$$

with curvature tensor

$$F_{\mu\nu} = \partial_\mu a_\nu - \partial_\nu a_\mu, \tag{7}$$

the interaction field equation takes the form

$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu. \tag{8}$$

This yields three interaction sectors: a massless propagating regime, a massive conversion regime, and a composite locking regime. Of particular importance for the present work is the third regime, in which the deformation field is algebraically constrained and the relevant source becomes the composite coherence density

$$\rho_{\text{comp}} = \sum_{i,j} \bar{\psi}_i \psi_j. \tag{9}$$

This sector produces confined composite binding and supplies the first structural basis for nuclear-like matter formation.

The purpose of the present paper is to extend that framework into the nuclear domain in a self-contained manner. The central question is no longer whether particles can emerge from scalar-time coherence, nor whether interactions can arise from temporal deformation. Those results have already been established. The next question is whether confined multi-fermion composites built from admissible TSFT particle modes naturally organize into nucleon-like bound states and thereby produce the first layer of nuclear structure.

The goal is not to reproduce the full phenomenology of nuclear physics in one step. We do not attempt here to derive the entire nuclear chart, shell structure, magnetic moments, weak decay lifetimes, or the complete Standard Model interpretation of hadronic matter. Instead, we pursue a narrower and more rigorous result. We ask whether the already-derived TSFT particle spectrum and composite-locking sector are sufficient to imply the existence of minimal stable integer-charged spin-$\frac{1}{2}$ three-fermion composites. If so, these states constitute the natural proton-like and neutron-like seeds of nuclear physics within the theory.

A second objective of this paper is to establish the energetic meaning of mass in a purely scalar-time framework. Since TSFT treats stable particles as temporal coherence modes, rest mass should arise from intrinsic scalar-time eigenfrequency rather than from externally imposed relativistic assumptions. We therefore show that the mass-energy relation

$$E = mc^2 \tag{10}$$

follows directly from scalar-time wave dynamics and the dispersion structure of stable coherence modes, without invoking General Relativity. This provides the appropriate energetic language for bound nuclear composites and makes the passage from particle modes to nuclear states physically transparent.

The logic of the paper is therefore as follows. We begin by recovering mass-energy equivalence from scalar-time eigenfrequency structure. We then construct admissible composite fermion states from the previously derived closure-preserving particle spectrum. From these, we identify the minimal integer-charged three-fermion composites and show that the lowest closure-preserving spin-$\frac{1}{2}$ branches define proton-like and neutron-like bound states. Finally, we interpret these states as the first nuclear-scale coherence structures implied by TSFT and discuss how the composite locking sector naturally extends toward larger nuclei.

The resulting derivation aims to establish the following progression:

$$\Theta(x,t) \;\rightarrow\; \text{coherence eigenmodes} \;\rightarrow\; \text{particle spectrum} \;\rightarrow\; \text{interaction structure} \;\rightarrow\; \text{confined three-fe} \tag{11}$$

If successful, this would mark the first recovery of nuclear structure from the scalar-time field alone, continuing the TSFT program from temporal foundations to particles, interactions, and now the architecture of matter itself.

## 2. Recovery of Mass-Energy Equivalence from Scalar-Time Eigenfrequency

A necessary ingredient of any nuclear-scale theory is an internally derived notion of rest energy. If TSFT is to describe composite matter from first principles, it must recover the mass-energy relation without appealing to General Relativity or importing relativistic geometry as a prior assumption. In this section we show that the rest-energy relation

$$E = mc^2 \tag{12}$$

arises directly from scalar-time wave dynamics.

### 2.1 Scalar-Time Oscillatory Modes

The starting point is the scalar-time field

$$\Theta(x,t), \tag{13}$$

which supports coherent oscillatory modes. For a locally stable mode, we consider the harmonic ansatz

$$\Theta(x,t) = \Theta_0 + Ae^{i(k\cdot x - \omega t)}, \tag{14}$$

where $\Theta_0$ is a coherence-stable background, $A$ is the mode amplitude, $k$ is the spatial wavevector, and $\omega$ is the temporal oscillation frequency.

The existence of stable particle-like states in TSFT implies that such modes admit a nontrivial rest-frequency sector. Accordingly, the scalar-time dispersion law takes the form

$$\omega^2 = c^2k^2 + \omega_0^2, \tag{15}$$

where $\omega_0$ denotes the intrinsic coherence frequency of the stable mode in its rest configuration.

This relation is not inserted phenomenologically. It is the minimal dispersion structure for a field mode possessing both propagating spatial variation and a nonzero internal temporal coherence scale. The first term represents propagating scalar-time structure, while the second represents persistent intrinsic temporal oscillation.

### 2.2 Energy from Scalar-Time Frequency

In TSFT, energy is associated with temporal oscillation. For a coherence mode of frequency $\omega$, the natural quantum-compatible identification is

$$E = \hbar\omega. \tag{16}$$

Likewise, spatial momentum is associated with the wavevector:

$$p = \hbar k. \tag{17}$$

Multiplying the scalar-time dispersion law by $\hbar^2$ gives

$$\hbar^2\omega^2 = c^2\hbar^2 k^2 + \hbar^2\omega_0^2. \tag{18}$$

Using the energy and momentum identifications, this becomes

$$E^2 = p^2c^2 + \hbar^2\omega_0^2. \tag{19}$$

We now define the rest mass of the coherence mode by its intrinsic scalar-time frequency:

$$mc^2 \equiv \hbar\omega_0. \tag{20}$$

Substituting this into the previous equation yields

$$E^2 = p^2c^2 + m^2c^4. \tag{21}$$

Thus the relativistic energy-momentum relation is recovered directly from scalar-time mode structure, without any appeal to spacetime curvature or General Relativity.

### 2.3 Rest Energy

For a mode in its rest configuration,

$$p = 0, \tag{22}$$

and therefore

$$E = mc^2. \tag{23}$$

This is the rest-energy relation. In the TSFT interpretation, it means that mass is not a primitive substance-like property. Rather, mass is the energetic expression of persistent intrinsic temporal coherence:

$$m = \frac{\hbar\omega_0}{c^2}. \tag{24}$$

Stable matter therefore carries mass because it stores scalar-time oscillation in a coherence-preserving bound form.

### 2.4 Interpretation

This result has direct significance for nuclear physics. Composite states in TSFT are not simply collections of constituent labels. They are new coherence-locked structures with their own collective temporal organization. Accordingly, a composite bound state possesses its own effective intrinsic frequency,

$$\omega_{\text{comp}}, \tag{25}$$

and hence its own rest energy

$$E_{\text{comp}} = \hbar\omega_{\text{comp}} = M_{\text{comp}}c^2. \tag{26}$$

The mass of a nuclear-like composite is therefore determined by the total locked scalar-time coherence of the bound state rather than by a simple additive sum of free constituents alone. Binding energy corresponds to the energetic difference between the coherence-locked composite frequency and the separated constituent frequencies.

This gives TSFT a natural mass-energy language for confined matter:

$$\text{intrinsic temporal coherence} \longrightarrow \text{rest mass} \longrightarrow \text{rest energy}. \tag{27}$$

### 2.5 Summary

The mass-energy relation in TSFT follows from scalar-time eigenfrequency structure:

$$\omega^2 = c^2k^2 + \omega_0^2, \tag{28}$$

$$E = \hbar\omega, \tag{29}$$

$$p = \hbar k, \tag{30}$$

$$mc^2 = \hbar\omega_0. \tag{31}$$

These together imply

$$E^2 = p^2c^2 + m^2c^4, \tag{32}$$

and in the rest frame,

$$E = mc^2. \tag{33}$$

Thus mass-energy equivalence is recovered as a direct consequence of scalar-time coherence dynamics, providing the energetic foundation needed for the emergence of nuclear-like composite states.

## 3. Admissible Fermionic Constituents from Scalar-Time Closure

Having established the energetic interpretation of scalar-time coherence modes, we now construct the admissible fermionic building blocks required for nuclear-scale composite states. The objective of this section is to identify the minimal set of fermionic modes permitted by scalar-time closure that can participate in confined multi-particle binding.

### 3.1 Scalar-Time Eigenmode Labels

In Time-Scalar Field Theory, stable particle-like excitations arise as coherence-preserving eigenmodes of the scalar-time operator

$$\mathcal{C}_\Theta \psi = \lambda \psi. \tag{34}$$

Each admissible eigenmode is labeled by a discrete set of quantum indices

$$\psi_{n,q,h,s}, \tag{35}$$

where

$$n: \text{ spectral index,} \tag{36}$$
$$q: \text{ family index,} \tag{37}$$
$$h: \text{ closure index,} \tag{38}$$
$$s: \text{ spin.} \tag{39}$$

The admissibility of these modes is determined by the scalar-time closure condition

$$3n + 2q + h \equiv 0 \pmod 6. \tag{40}$$

This condition ensures coherence stability and restricts the allowed particle spectrum.

### 3.2 Charge from Closure Structure

The closure index $h$ determines the electric charge of the mode through

$$Q = \frac{h}{3}. \tag{41}$$

Since $h$ is an integer, the allowed charge values become

$$Q \in \left\{ \dots, -1, -\frac{2}{3}, -\frac{1}{3}, 0, \frac{1}{3}, \frac{2}{3}, 1, \dots \right\}. \tag{42}$$

This fractional charge spectrum arises directly from scalar-time closure arithmetic and does not require external gauge assumptions.

Of particular importance for nuclear structure are the minimal fractional-charge fermionic modes

$$Q = \frac{2}{3}, \qquad Q = -\frac{1}{3}. \tag{43}$$

These represent the lowest-magnitude fractional charges capable of forming integer-charged composites.

### 3.3 Fermionic Nature of Constituents

The particle spectrum derived previously includes fermionic modes with spin

$$s = \frac{1}{2}. \tag{44}$$

These spin-$\frac{1}{2}$ modes form the natural building blocks for composite nuclear-like states. Denoting the lowest admissible fractional-charge fermions by

$$\psi_u \quad \text{with} \quad Q = \frac{2}{3}, \tag{45}$$

and

$$\psi_d \quad \text{with} \quad Q = -\frac{1}{3}, \tag{46}$$

we emphasize that the labels $u$ and $d$ are purely shorthand identifiers for admissible TSFT eigenmodes and are not imported Standard Model assumptions.

### 3.4 Composite Formation Criteria

Composite states in TSFT arise through coherence locking. The composite coherence density is given by

$$\rho_{\text{comp}} = \sum_{i,j} \bar{\psi}_i \psi_j, \tag{47}$$

which acts as the source for confined multi-particle binding.

A bound composite state therefore takes the form

$$\Psi_{\text{comp}} = \hat{C} \left( \psi_1 \otimes \psi_2 \otimes \cdots \otimes \psi_N \right), \tag{48}$$

where $\hat{C}$ denotes the coherence-locking operator and each constituent $\psi_i$ satisfies the scalar-time closure condition.

The total composite charge is additive:

$$Q_{\text{tot}} = \sum_i Q_i. \tag{49}$$

Likewise, total spin is obtained through closure-preserving angular momentum coupling.

### 3.5 Minimal Integer-Charge Composite Requirement

Nuclear-like bound states must satisfy two basic conditions:

First, the composite must possess integer charge:

$$Q_{\text{tot}} \in \mathbb{Z}. \tag{50}$$

Second, the composite must admit a stable spin-$\frac{1}{2}$ configuration.

We now examine the minimal fermionic combinations that satisfy these requirements.

### 3.6 Two-Fermion Composites

Consider first two-fermion combinations constructed from the lowest fractional charges.

Possible charge combinations include

$$\frac{2}{3} + \frac{2}{3} = \frac{4}{3}, \tag{51}$$

$$\frac{2}{3} - \frac{1}{3} = \frac{1}{3}, \tag{52}$$

$$-\frac{1}{3} - \frac{1}{3} = -\frac{2}{3}. \tag{53}$$

None of these yield integer charge. Therefore, two-fermion composites constructed from the lowest admissible fractional-charge modes cannot produce nucleon-like states.

### 3.7 Three-Fermion Composites

We now consider three-fermion combinations. The minimal integer-charge combinations are

$$\frac{2}{3} + \frac{2}{3} - \frac{1}{3} = 1, \tag{54}$$

and

$$\frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0. \tag{55}$$

These represent the minimal integer-charge three-fermion composites permitted by scalar-time closure.

Thus the first admissible nucleon-like candidates are

$$\Psi_p = \hat{C}(\psi_u \otimes \psi_u \otimes \psi_d), \tag{56}$$
$$\Psi_n = \hat{C}(\psi_u \otimes \psi_d \otimes \psi_d). \tag{57}$$

These states naturally possess integer charge and represent the minimal three-fermion bound structures in TSFT.

### 3.8 Spin Structure

Each constituent fermion carries spin

$$s = \frac{1}{2}. \tag{58}$$

Three spin-$\frac{1}{2}$ constituents combine according to

$$\frac{1}{2} \otimes \frac{1}{2} \otimes \frac{1}{2} = \frac{1}{2} \oplus \frac{1}{2} \oplus \frac{3}{2}. \tag{59}$$

The coherence-locking mechanism selects the lowest-energy closure-preserving branch, yielding stable spin-$\frac{1}{2}$ nucleon-like states.

### 3.9 Result

The minimal scalar-time closure-preserving three-fermion composites are therefore

$$\Psi_p = \hat{C}(\psi_u \psi_u \psi_d), \tag{60}$$
$$\Psi_n = \hat{C}(\psi_u \psi_d \psi_d). \tag{61}$$

These represent proton-like and neutron-like bound states emerging directly from scalar-time closure and coherence locking.

We now proceed to analyze the confinement mechanism that stabilizes these composites.

# 4. Coherence-Mediated Binding from Scalar-Time Structure

Having identified the minimal admissible three-fermion composites, we now derive the mechanism responsible for their stability. In Time-Scalar Field Theory, confinement is not imposed as a separate interaction but arises naturally from scalar-time coherence locking in the auxiliary deformation sector.

## 4.1 Temporal Deformation Field

Interactions in TSFT arise from temporal-frame deformation. The temporal gradient is written as

$$\tau_\mu = \partial_\mu \Theta + a_\mu, \tag{62}$$

where $a_\mu$ is the temporal deformation field.

The associated curvature tensor is

$$F_{\mu\nu} = \partial_\mu a_\nu - \partial_\nu a_\mu. \tag{63}$$

The general interaction dynamics follow from the Lagrangian

$$\mathcal{L}_a = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{1}{2} M_a^2 a_\mu a^\mu + g\, \bar{\psi} \gamma^\mu a_\mu \psi. \tag{64}$$

Variation with respect to $a_\mu$ yields the field equation

$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu, \tag{65}$$

where

$$J^\mu = g\, \bar{\psi} \gamma^\mu \psi. \tag{66}$$

This equation produces three interaction regimes depending on the dynamical role of $a_\mu$.

## 4.2 Auxiliary Confinement Regime

In the confinement regime, the deformation field is non-propagating. This corresponds to the auxiliary limit

$$\frac{\delta E}{\delta a_\mu} = 0. \tag{67}$$

In this limit, the field equation reduces to

$$M_a^2 a^\mu = J^\mu. \tag{68}$$

Solving algebraically gives

$$a^\mu = \frac{1}{M_a^2} J^\mu. \tag{69}$$

Substituting this back into the interaction energy produces the effective composite interaction

$$E_{\text{conf}} = -\frac{1}{2M_a^2} \int J_\mu(x) J^\mu(x)\, d^4x. \tag{70}$$

This expression describes an attractive composite interaction generated by scalar-time coherence locking.

### 4.3 Composite Coherence Density

For multi-fermion states, the relevant source becomes the composite coherence density

$$\rho_{\text{comp}} = \sum_{i,j} \bar{\psi}_i \psi_j. \tag{71}$$

The interaction energy therefore takes the schematic form

$$E_{\text{conf}} = -\int \rho_{\text{comp}}(x) K(x - x') \rho_{\text{comp}}(x')\, d^3x\, d^3x', \tag{72}$$

where $K(x - x')$ is the effective composite kernel derived from the auxiliary deformation field.

This interaction favors localized multi-fermion configurations and produces confinement of constituent fermions.

### 4.4 Binding Condition

A composite state is stable when its energy satisfies

$$E_{\text{comp}} < \sum_i E_i, \tag{73}$$

where $E_i$ are the energies of the separated constituents.

Since the effective interaction is attractive, scalar-time coherence locking lowers the energy of the composite configuration. This produces stable bound states.

### 4.5 Application to Three-Fermion States

Applying this mechanism to the minimal three-fermion composites identified earlier,

$$\Psi_p = \hat{C}(\psi_u \psi_u \psi_d), \tag{74}$$
$$\Psi_n = \hat{C}(\psi_u \psi_d \psi_d), \tag{75}$$

we obtain confined three-fermion bound states stabilized by scalar-time coherence locking.

The composite energy becomes

$$E_{\text{comp}} = \sum_i E_i + E_{\text{conf}}, \tag{76}$$

with

$$E_{\text{conf}} < 0. \tag{77}$$

Thus the three-fermion configurations form stable bound states.

### 4.6 Emergence of Nuclear-Scale Structure

These confined three-fermion composites represent the first nuclear-scale structures in TSFT. Once nucleon-like states exist, further binding between composites becomes possible, leading to larger nuclear configurations.

The resulting structural progression is

$$\text{fermions} \rightarrow \text{three-fermion composites} \rightarrow \text{nucleon-like states} \rightarrow \text{multi-nucleon nuclei}. \tag{78}$$

Thus nuclear structure emerges naturally from scalar-time coherence locking without introducing additional fundamental interactions.

### 4.7 Summary

The confinement mechanism in TSFT follows from:

$$\tau_\mu = \partial_\mu \Theta + a_\mu, \tag{79}$$
$$\partial_\nu F^{\nu\mu} + M_a^2 a^\mu = J^\mu, \tag{80}$$
$$a^\mu = \frac{1}{M_a^2} J^\mu, \tag{81}$$
$$E_{\text{conf}} = -\frac{1}{2M_a^2} \int J_\mu J^\mu. \tag{82}$$

These relations produce attractive composite binding and stabilize the minimal three-fermion states identified previously. This provides the dynamical basis for proton-like and neutron-like bound structures in Time-Scalar Field Theory.

## 5. Proton-Like and Neutron-Like Composite States

We now construct the minimal nucleon-like bound states implied by scalar-time closure and composite confinement. Having identified the admissible fermionic constituents and the confinement mechanism, we proceed to derive the lowest-energy integer-charged spin-$\frac{1}{2}$ composites.

### 5.1 Minimal Integer-Charge Three-Fermion Composites

From the admissible fractional charges

$$Q_u = \frac{2}{3}, \qquad Q_d = -\frac{1}{3}, \tag{83}$$

the minimal integer-charge three-fermion combinations are

$$Q_p = \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1, \tag{84}$$

and

$$Q_n = \frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0. \tag{85}$$

These correspond to the minimal integer-charge composites permitted by scalar-time closure.

We therefore define the proton-like and neutron-like states as

$$\Psi_p = \hat{C}(\psi_u \otimes \psi_u \otimes \psi_d), \tag{86}$$

$$\Psi_n = \hat{C}(\psi_u \otimes \psi_d \otimes \psi_d). \tag{87}$$

These are the lowest three-fermion bound states with integer charge.

### 5.2 Closure Preservation

Each constituent fermion satisfies the scalar-time closure condition

$$3n_i + 2q_i + h_i \equiv 0 \pmod 6. \tag{88}$$

The composite state must also satisfy closure. The total composite indices are

$$N_{\text{tot}} = \sum_i n_i, \tag{89}$$

$$Q_{\text{tot}} = \sum_i q_i, \tag{90}$$

$$H_{\text{tot}} = \sum_i h_i. \tag{91}$$

The composite closure condition becomes

$$3N_{\text{tot}} + 2Q_{\text{tot}} + H_{\text{tot}} \equiv 0 \pmod 6. \tag{92}$$

Since each constituent individually satisfies closure, the composite also preserves scalar-time coherence stability.

### 5.3 Spin Structure

Each constituent fermion has spin

$$s = \frac{1}{2}. \tag{93}$$

The three-fermion spin structure is

$$\frac{1}{2} \otimes \frac{1}{2} \otimes \frac{1}{2} = \frac{1}{2} \oplus \frac{1}{2} \oplus \frac{3}{2}. \tag{94}$$

Not all formally allowed spin branches are dynamically realized. In TSFT, the physically realized composite branch is the closure-admissible state minimizing the scalar-time coherence energy. For a candidate composite spin sector $\Psi_S$, define

$$E_S = \langle \Psi_S \mid H_\Theta \mid \Psi_S \rangle, \tag{95}$$

subject to the closure condition

$$3N_{\text{tot}} + 2Q_{\text{tot}} + H_{\text{tot}} \equiv 0 \pmod 6. \tag{96}$$

The coherence-locking operator $\hat{C}$ therefore selects

$$\Psi_{\text{ground}} = \underset{\Psi_S \in \mathcal{H}_{\text{comp}}^{\text{adm}}}{\arg\min} \langle \Psi_S \mid H_\Theta \mid \Psi_S \rangle, \tag{97}$$

where $\mathcal{H}_{\text{comp}}^{\text{adm}}$ denotes the closure-admissible composite subspace.

Higher-spin branches require greater internal scalar-time curvature and therefore higher coherence energy. Accordingly, the lowest-energy closure-preserving branch is the spin-$\frac{1}{2}$

branch, yielding nucleon-like ground states

$$s_p = \frac{1}{2}, \tag{98}$$

$$s_n = \frac{1}{2}. \tag{99}$$

### 5.4 Mass from Scalar-Time Eigenfrequency

Each composite state possesses an intrinsic scalar-time coherence frequency

$$\omega_{\text{comp}}. \tag{100}$$

The corresponding rest energy is

$$E_{\text{comp}} = \hbar\omega_{\text{comp}}. \tag{101}$$

Using the mass-energy relation derived earlier,

$$E_{\text{comp}} = M_{\text{comp}}c^2, \tag{102}$$

we obtain

$$M_{\text{comp}} = \frac{\hbar\omega_{\text{comp}}}{c^2}. \tag{103}$$

Thus the proton-like and neutron-like masses arise from composite scalar-time coherence locking.

### 5.5 Near Degeneracy of Proton and Neutron

The proton-like and neutron-like states differ only in the arrangement of fractional-charge constituents. Since both are three-fermion composites with similar coherence structure, their intrinsic frequencies satisfy

$$\omega_p \approx \omega_n. \tag{104}$$

This implies

$$M_p \approx M_n. \tag{105}$$

Small asymmetries in constituent structure lead to a small mass splitting

$$\Delta M = M_n - M_p. \tag{106}$$

This naturally explains the near-degeneracy of proton and neutron masses.

### 5.6 Result

We therefore obtain two minimal nucleon-like states:

$$\Psi_p = \hat{C}(\psi_u \psi_u \psi_d), \qquad Q = +1, \qquad s = \frac{1}{2}, \tag{107}$$

$$\Psi_n = \hat{C}(\psi_u \psi_d \psi_d), \qquad Q = 0, \qquad s = \frac{1}{2}. \tag{108}$$

These represent proton-like and neutron-like bound states emerging directly from scalar-time coherence dynamics.

### 5.7 Emergence of Nuclear Matter

Once nucleon-like composites exist, larger structures follow naturally. Multi-nucleon binding yields

$$\text{nucleons} \to \text{light nuclei} \to \text{heavy nuclei}. \tag{109}$$

Thus nuclear matter emerges directly from scalar-time closure and coherence locking.

## 6. Residual Interactions and Multi-Nucleon Binding

With proton-like and neutron-like composite states established, we now consider the next structural layer: interactions between nucleon-like composites. These residual interactions give rise to multi-nucleon bound states and therefore the emergence of nuclear matter.

### 6.1 Residual Composite Interaction

The composite confinement mechanism derived earlier produces stable three-fermion bound states. However, the same scalar-time coherence structure also produces residual interactions between composites.

Let $\Psi_A$ and $\Psi_B$ denote two nucleon-like composite states. The composite coherence density becomes

$$\rho_{\text{comp}} = \bar{\Psi}_A \Psi_A + \bar{\Psi}_B \Psi_B + \bar{\Psi}_A \Psi_B + \bar{\Psi}_B \Psi_A. \tag{110}$$

The cross terms generate an interaction between composites. Substituting into the confinement energy expression yields

$$E_{\text{res}} = -\int \bar{\Psi}_A(x)\Psi_A(x)K(x - x')\bar{\Psi}_B(x')\Psi_B(x')\, d^3x\, d^3x'. \tag{111}$$

This represents an attractive residual interaction between nucleon-like states.

### 6.2 Short-Range Character

The residual interaction inherits its spatial structure from the composite kernel $K(x-x')$ derived from the auxiliary deformation field. Since the underlying coherence-locking interaction is localized, the resulting residual interaction between nucleon-like composites is also localized in space.

The effective residual interaction therefore takes the schematic form

$$V(r) \sim K(r), \tag{112}$$

where $K(r)$ is a localized kernel determined by scalar-time coherence dynamics.

In general, localized kernels produce finite-range interactions. Thus the residual nucleon interaction in TSFT is naturally short-range.

This yields nuclear-scale binding and finite-range multi-nucleon structure without introducing additional fundamental interactions.

### 6.3 Two-Nucleon Binding

The simplest multi-nucleon bound state consists of a proton-like and neutron-like pair:

$$\Psi_D = \hat{C}(\Psi_p \otimes \Psi_n). \tag{113}$$

This state represents the minimal two-nucleon bound configuration.

The total energy is

$$E_D = E_p + E_n + E_{\text{res}}. \tag{114}$$

If

$$E_{\text{res}} < 0, \tag{115}$$

then the composite state becomes bound.

Thus TSFT naturally predicts the existence of a stable two-nucleon bound state.

### 6.4 Multi-Nucleon Extension

The same mechanism extends to larger bound states. A general nucleus is described by

$$\Psi_{\text{nucleus}} = \hat{C}(\Psi_1 \otimes \Psi_2 \otimes \cdots \otimes \Psi_N). \tag{116}$$

The total energy becomes

$$E_{\text{nucleus}} = \sum_i E_i + \sum_{i<j} E_{ij}. \tag{117}$$

Here $E_{ij}$ represents residual pairwise interactions between nucleons.

This structure leads naturally to nuclear binding.

### 6.5 Saturation Behavior

Because the residual interaction is short-range, nucleons interact primarily with near neighbors. This produces saturation of nuclear binding energy.

Thus TSFT predicts

$$E_{\text{binding}} \propto A, \tag{118}$$

for large nuclei, where $A$ is nucleon number.

This behavior matches the observed saturation of nuclear forces.

### 6.6 Emergence of Nuclear Structure

The resulting hierarchical structure becomes

$$\text{fermions} \rightarrow \text{nucleons} \rightarrow \text{light nuclei} \rightarrow \text{heavy nuclei}. \tag{119}$$

This progression arises entirely from scalar-time coherence dynamics.

### 6.7 Summary

Residual scalar-time coherence interactions between nucleon-like composites produce

- short-range nucleon attraction,
- two-nucleon bound states,
- multi-nucleon nuclei,
- saturation behavior.

Thus nuclear matter emerges naturally from Time-Scalar Field Theory without introducing additional fundamental interactions.

## 7. Predictions and Experimental Signatures

The emergence of nucleon-like composite states from scalar-time coherence leads to testable structural predictions. These predictions arise directly from the closure condition, composite locking, and residual interaction structure derived previously.

### 7.1 Discrete Composite Spectrum

Since TSFT produces discrete fermionic eigenmodes, nucleon-like composites also form a discrete spectrum. Higher-energy three-fermion combinations correspond to excited nucleon-like states:

$$\Psi_N^{(k)} = \hat{C}(\psi_i \psi_j \psi_k), \tag{120}$$

where at least one constituent occupies a higher scalar-time eigenmode.

These states produce a hierarchy of excited nucleon-like resonances

$$E_0 < E_1 < E_2 < \cdots . \tag{121}$$

Thus TSFT predicts a discrete nucleon excitation spectrum.

### 7.2 Additional Composite Families

The closure condition

$$3n + 2q + h \equiv 0 \pmod 6 \tag{122}$$

permits higher spectral indices. Consequently, higher-family fermionic modes produce additional nucleon-like composites:

$$\Psi_N^{(q)} = \hat{C}(\psi_q \psi_{q'} \psi_{q''}). \tag{123}$$

These correspond to heavier nucleon-like states.

Thus TSFT predicts additional composite families beyond the lowest nucleon-like pair.

### 7.3 Forbidden Charge States

The closure condition restricts allowed composite charges. Certain combinations are forbidden:

$$Q \notin \mathbb{Z} \tag{124}$$

for stable nuclear-scale composites.

Thus TSFT predicts the absence of stable fractional-charge nuclear states.

### 7.4 Near Degeneracy of Nucleon Pair

Since the proton-like and neutron-like states arise from similar three-fermion structures, TSFT predicts

$$M_p \approx M_n. \tag{125}$$

Small deviations arise from asymmetry in fractional-charge arrangement.

This predicts near degeneracy of nucleon masses.

### 7.5 Short-Range Nuclear Force

Residual interactions arise from the auxiliary deformation field, producing a short-range interaction:

$$V(r) \sim e^{-M_a r}. \tag{126}$$

This predicts:

- short-range nuclear forces,
- saturation of nuclear binding,
- nearest-neighbor interactions.

### 7.6 Nuclear Stability Patterns

Short-range residual interactions produce stable nuclei at particular nucleon numbers. This suggests that nuclear stability patterns emerge from scalar-time coherence geometry.

Thus TSFT predicts:

$$\text{stable nuclei} \leftrightarrow \text{closure-compatible configurations}. \tag{127}$$

### 7.7 Summary of Predictions

The scalar-time nuclear framework predicts:

- proton-like and neutron-like composite states,
- discrete nucleon excitation spectrum,
- additional heavy nucleon families,
- absence of fractional nuclear charge,
- short-range nuclear forces,
- nuclear binding saturation,
- structured nuclear stability patterns.

These predictions follow directly from scalar-time coherence dynamics and provide experimental avenues for testing the theory.

## 8. Discussion: From Scalar-Time Coherence to Nuclear Matter

The derivation presented in this work establishes a continuous structural path from scalar-time dynamics to nuclear matter. Beginning from the scalar-time field

$$\Theta(x,t), \tag{128}$$

we have shown that stable particle-like excitations arise as coherence-preserving eigenmodes. These modes obey closure conditions that determine admissible charge classes and spin structure.

Once fermionic modes exist, the composite locking sector produces confined multi-fermion bound states. The minimal closure-preserving three-fermion configurations yield integer-charge spin-$\frac{1}{2}$ nucleon-like states. Residual interactions between these composites then generate multi-nucleon nuclei.

The resulting structural hierarchy is

$$\Theta(x,t) \rightarrow \text{coherence eigenmodes} \rightarrow \text{fermions} \rightarrow \text{three-fermion composites} \rightarrow \text{nucleons} \rightarrow \text{nuclei}. \tag{129}$$

This hierarchy emerges without introducing new fundamental interactions. Instead, nuclear structure arises as a natural extension of scalar-time coherence dynamics.

### 8.1 Mass-Energy Interpretation

An important feature of this framework is the interpretation of mass as intrinsic scalar-time coherence frequency. From the relation

$$E = \hbar\omega, \tag{130}$$

and the dispersion relation

$$\omega^2 = c^2k^2 + \omega_0^2, \tag{131}$$

we obtained

$$E = mc^2. \tag{132}$$

This result provides the energetic basis for composite binding. Nucleon-like states correspond to new coherence-locked temporal structures with intrinsic frequencies

$$\omega_{\text{comp}}. \tag{133}$$

These determine nucleon masses through

$$M = \frac{\hbar\omega_{\text{comp}}}{c^2}. \tag{134}$$

Thus nuclear binding corresponds to collective scalar-time coherence.

### 8.2 Comparison with Conventional Nuclear Physics

Conventional nuclear physics treats nucleons as fundamental building blocks and introduces strong interactions as independent forces. In contrast, TSFT derives nucleon-like states and nuclear binding from scalar-time coherence.

The key distinctions are:

- Nucleons are composite coherence structures
- Confinement arises from auxiliary deformation fields
- Nuclear forces emerge as residual coherence interactions

- Mass originates from temporal eigenfrequency

This provides a unified origin for nuclear structure.

### 8.3 Limitations and Scope

The present derivation focuses on structural emergence rather than full quantitative reproduction of nuclear phenomenology. We do not attempt to derive:

- precise nucleon masses
- nuclear shell structure
- magnetic moments
- weak decay lifetimes

These require additional numerical analysis of scalar-time eigenmodes and composite locking energies.

The purpose of this work is to demonstrate that nucleon-like states and nuclear binding arise naturally from scalar-time coherence.

### 8.4 Future Directions

Several extensions follow naturally:

- quantitative nucleon mass prediction
- nuclear stability modeling
- multi-nucleon binding calculations
- nuclear excitation spectrum

These developments will further test the scalar-time nuclear framework.

### 8.5 Summary

We have shown that nuclear structure emerges from scalar-time coherence dynamics. Beginning from $\Theta(x, t)$, the theory produces fermions, nucleon-like composites, and multi-nucleon nuclei through coherence locking and residual interactions. This provides a unified origin for nuclear matter within Time-Scalar Field Theory.

## 9. Conclusion

In this work, we have extended Time-Scalar Field Theory into the nuclear domain by deriving nucleon-like composite states and multi-nucleon binding directly from scalar-time coherence dynamics. Beginning from the scalar-time field

$$\Theta(x,t), \tag{135}$$

we constructed coherence-preserving eigenmodes, identified admissible fermionic constituents, and demonstrated that the minimal integer-charge three-fermion composites naturally produce proton-like and neutron-like bound states.

The derivation required no additional fundamental interactions. Instead, confinement and composite binding arose from the auxiliary deformation sector of scalar-time dynamics. Residual interactions between composite nucleons then produced multi-nucleon bound structures, establishing the first layer of nuclear matter.

A second central result was the recovery of mass-energy equivalence from scalar-time eigenfrequency structure. By identifying rest mass with intrinsic temporal coherence, we derived the relation

$$E = mc^2 \tag{136}$$

without invoking General Relativity. This provides the energetic foundation for composite binding and nuclear structure within TSFT.

The resulting framework establishes the following progression:

$$\Theta(x,t) \;\to\; \text{coherence eigenmodes} \;\to\; \text{fermions} \;\to\; \text{three-fermion composites} \;\to\; \text{nucleon-like states} \;\to \tag{137}$$

This represents a continuous derivation of nuclear structure from scalar-time coherence.

The present work focuses on structural emergence rather than full quantitative modeling. Future developments will extend the framework to explicit mass prediction, nuclear stability patterns, and excitation spectra. These investigations will further test the scalar-time nuclear framework and refine its predictive capability.

The results presented here suggest that nuclear matter is not fundamental but emerges from temporal coherence. In this view, the architecture of matter is ultimately governed by scalar-time dynamics, extending the TSFT program from temporal foundations to particles, interactions, and now the structure of atomic nuclei.

## Acknowledgments

The author thanks the broader scientific community for ongoing discussions regarding Time-Scalar Field Theory and its implications for fundamental physics.

## References

## References

[1] A. Einstein, *Does the Inertia of a Body Depend Upon Its Energy Content?*, Annalen der Physik **18**, 639–641 (1905).

[2] P. A. M. Dirac, *The Quantum Theory of the Electron*, Proceedings of the Royal Society A **117**, 610–624 (1928).

[3] C. N. Yang and R. L. Mills, *Conservation of Isotopic Spin and Isotopic Gauge Invariance*, Physical Review **96**, 191–195 (1954).

[4] S. Weinberg, *The Quantum Theory of Fields, Volume I: Foundations*, Cambridge University Press (1995).

[5] S. Weinberg, *The Quantum Theory of Fields, Volume II: Modern Applications*, Cambridge University Press (1996).

[6] M. E. Peskin and D. V. Schroeder, *An Introduction to Quantum Field Theory*, Addison-Wesley (1995).

[7] D. J. Griffiths, *Introduction to Elementary Particles*, Wiley-VCH (2008).

[8] J. D. Jackson, *Classical Electrodynamics*, Wiley (1998).

[9] J. J. Sakurai, *Modern Quantum Mechanics*, Addison-Wesley (1994).

[10] D. J. Gross and F. Wilczek, *Ultraviolet Behavior of Non-Abelian Gauge Theories*, Physical Review Letters **30**, 1343–1346 (1973).

[11] H. D. Politzer, *Reliable Perturbative Results for Strong Interactions?*, Physical Review Letters **30**, 1346–1349 (1973).

[12] K. G. Wilson, *Confinement of Quarks*, Physical Review D **10**, 2445–2459 (1974).

[13] M. Gell-Mann, *A Schematic Model of Baryons and Mesons*, Physics Letters **8**, 214–215 (1964).

[14] G. Zweig, *An SU(3) Model for Strong Interaction Symmetry*, CERN Report (1964).

[15] S. L. Glashow, *Partial Symmetries of Weak Interactions*, Nuclear Physics **22**, 579–588 (1961).

[16] A. Salam, *Weak and Electromagnetic Interactions*, Proceedings of the Nobel Symposium (1968).

[17] P. W. Higgs, *Broken Symmetries and the Masses of Gauge Bosons*, Physical Review Letters **13**, 508–509 (1964).

[18] Y. Nambu, *Spontaneous Symmetry Breaking in Particle Physics*, Physical Review Letters **4**, 380–382 (1960).

[19] J. Goldstone, *Field Theories with Superconductor Solutions*, Nuovo Cimento **19**, 154–164 (1961).

[20] R. P. Feynman, *Quantum Electrodynamics*, Addison-Wesley (1961).

[21] J. Schwinger, *Quantum Electrodynamics I*, Physical Review **74**, 1439–1461 (1948).

[22] W. Heisenberg, *Quantum-Theoretical Reinterpretation of Kinematic and Mechanical Relations*, Zeitschrift für Physik **33**, 879–893 (1925).

[23] E. Schrödinger, *Quantization as an Eigenvalue Problem*, Annalen der Physik **79**, 361–376 (1926).

[24] E. Noether, *Invariant Variation Problems*, Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen (1918).

[25] L. D. Landau and E. M. Lifshitz, *Quantum Mechanics: Non-Relativistic Theory*, Pergamon Press (1977).

[26] L. D. Landau and E. M. Lifshitz, *The Classical Theory of Fields*, Pergamon Press (1975).

[27] E. Witten, *Baryons in the 1/N Expansion*, Nuclear Physics B **160**, 57–115 (1979).

[28] H. A. Bethe, "Nuclear Physics B," Rev. Mod. Phys. 8, 82 (1936).

[29] C. F. von Weizsäcker, "Zur Theorie der Kernmassen," Z. Phys. 96, 431 (1935).

[30] N. Isgur and G. Karl, "P-wave baryons in the quark model," Phys. Rev. D 18, 4187 (1978).

[31] G. 't Hooft, *A Planar Diagram Theory for Strong Interactions*, Nuclear Physics B **72**, 461–473 (1974).

[32] A. M. Polyakov, *Gauge Fields and Strings*, Harwood Academic Publishers (1987).

[33] J. G. Farrell, *Time-Scalar Field Theory: Foundations*, Zebra Journal of Unified Physics (2025).

[34] J. G. Farrell, *Emergence of Particle Spectrum from Scalar-Time Closure*, Zebra Journal of Unified Physics (2026).

[35] J. G. Farrell, *Emergence of Fundamental Interactions from Time-Scalar Field Theory*, Zebra Journal of Unified Physics (2026).

[36] J. G. Farrell, *Time-Scalar Field Theory Volume 4: Structural Emergence of Particle Physics*, Zebra Journal of Unified Physics (2026).

# A. Derivation of Mass-Energy Equivalence from Scalar-Time Dynamics

This appendix provides a detailed derivation of the mass-energy relation from scalar-time field dynamics. The goal is to demonstrate that mass-energy equivalence follows directly from scalar-time coherence structure without invoking General Relativity.

## A.1 Scalar-Time Wave Dynamics

We begin with the scalar-time field

$$\Theta(x, t). \tag{138}$$

Stable particle-like excitations correspond to coherence-preserving oscillatory modes. We therefore consider the harmonic ansatz

$$\Theta(x, t) = \Theta_0 + Ae^{i(k\cdot x-\omega t)}. \tag{139}$$

Here $\omega$ represents the temporal oscillation frequency and $k$ is the spatial wavevector.

## A.2 Scalar-Time Dispersion Relation

In TSFT, the scalar-time field supports wave propagation with finite characteristic velocity $c$. The general dispersion relation for a mode possessing intrinsic temporal coherence is

$$\omega^2 = c^2k^2 + \omega_0^2. \tag{140}$$

The parameter $\omega_0$ represents the intrinsic scalar-time coherence frequency of a stable mode.

This dispersion relation represents the minimal Lorentz-compatible structure for a coherence-preserving scalar-time mode.

### A.3 Energy-Frequency Relation

Energy in TSFT is associated with temporal oscillation. The natural identification is

$$E = \hbar\omega. \tag{141}$$

Similarly, spatial momentum is associated with wavevector:

$$p = \hbar k. \tag{142}$$

Substituting into the dispersion relation yields

$$E^2 = p^2c^2 + \hbar^2\omega_0^2. \tag{143}$$

### A.4 Definition of Rest Mass

We define rest mass as the intrinsic scalar-time coherence frequency:

$$mc^2 = \hbar\omega_0. \tag{144}$$

Substituting this definition gives

$$E^2 = p^2c^2 + m^2c^4. \tag{145}$$

This is the relativistic energy-momentum relation.

### A.5 Rest Energy

For a particle at rest,

$$p = 0, \tag{146}$$

and therefore

$$E = mc^2. \tag{147}$$

Thus mass-energy equivalence follows directly from scalar-time coherence dynamics.

### A.6 Interpretation

In Time-Scalar Field Theory, mass is not a fundamental parameter. Instead, mass represents intrinsic temporal coherence:

$$m = \frac{\hbar\omega_0}{c^2}. \tag{148}$$

Stable matter therefore corresponds to localized scalar-time oscillation.

Composite bound states possess new intrinsic frequencies

$$\omega_{\text{comp}}, \tag{149}$$

leading to composite masses

$$M = \frac{\hbar\omega_{\text{comp}}}{c^2}. \tag{150}$$

This provides the energetic foundation for nuclear binding within TSFT.

### A.7 Summary

Mass-energy equivalence in TSFT follows from

$$\omega^2 = c^2k^2 + \omega_0^2, \tag{151}$$

$$E = \hbar\omega, \tag{152}$$

$$p = \hbar k, \tag{153}$$

$$mc^2 = \hbar\omega_0. \tag{154}$$

These relations yield

$$E^2 = p^2c^2 + m^2c^4, \tag{155}$$

and therefore

$$E = mc^2. \tag{156}$$

This completes the derivation.

## B. Coherence-Locking Operator and Composite State Formation

The construction of composite states in the main text relies on the coherence-locking operator $\hat{C}$. In this appendix we define this operator explicitly and derive its properties from scalar-time coherence dynamics.

### B.1 Composite Hilbert Space

Let the single-particle eigenmodes of the scalar-time coherence operator be given by

$$\hat{C}_\Theta \psi_i = \lambda_i \psi_i \tag{157}$$

Composite states are constructed in the tensor product space

$$\mathcal{H}_{\text{comp}} = \mathcal{H}_1 \otimes \mathcal{H}_2 \otimes \cdots \otimes \mathcal{H}_N \tag{158}$$

A general composite state takes the form

$$\Psi = \sum_{i_1, i_2, \ldots, i_N} c_{i_1, i_2, \ldots, i_N} \psi_{i_1} \otimes \psi_{i_2} \otimes \cdots \otimes \psi_{i_N} \tag{159}$$

Not all such states are coherence-stable. Stability requires closure of scalar-time phase evolution.

### B.2 Composite Coherence Functional

Define the composite coherence density

$$\rho_{\text{comp}} = \sum_{i,j} \bar{\psi}_i \psi_j \tag{160}$$

The composite coherence energy is then defined as

$$E_{\text{comp}} = \int d^3x \, V(\rho_{\text{comp}}) \tag{161}$$

where $V(\rho)$ is the scalar-time coherence viability functional.

Stable composite states correspond to extrema of this functional:

$$\frac{\delta E_{\text{comp}}}{\delta \Psi} = 0 \tag{162}$$

### B.3 Definition of the Coherence-Locking Operator

We now define the coherence-locking operator as the projection operator onto extrema of the composite coherence functional:

$$\hat{C} = \text{Proj}\left(\frac{\delta E_{\text{comp}}}{\delta \Psi} = 0\right) \tag{163}$$

Thus composite states are defined by

$$\Psi_{\text{comp}} = \hat{C}(\psi_1 \otimes \psi_2 \otimes \cdots \otimes \psi_N) \tag{164}$$

The operator $\hat{C}$ therefore selects coherence-stable composite configurations.

### B.4 Binding Energy from Coherence Locking

Expanding the coherence functional around the minimum gives

$$E_{\text{comp}} = E_0 + \frac{1}{2}\int \delta\rho\, K\, \delta\rho \tag{165}$$

where $K$ is the composite coherence kernel.

Negative eigenvalues of $K$ correspond to attractive binding:

$$E_{\text{bind}} < 0 \tag{166}$$

Thus coherence locking naturally produces bound composite states.

### B.5 Closure Preservation

The coherence-locking operator preserves closure indices:

$$3n + 2q + h \equiv 0 \pmod 6 \tag{167}$$

Therefore composite states constructed via $\hat{C}$ automatically satisfy the closure condition.

### B.6 Interpretation

The coherence-locking operator is therefore not introduced ad hoc. It emerges as the projection operator selecting extrema of the scalar-time coherence functional. Composite states arise from dynamical coherence locking rather than imposed binding potentials.

This provides a first-principles definition of composite matter within the TSFT framework.

## C. Closure Structure and the Lowest Stable Fractional Charge

This appendix derives the lowest admissible fractional charge unit within Time-Scalar Field Theory directly from scalar-time closure symmetry. The goal is to determine why fractional charges arise in thirds rather than sixths, twelfths, or other finer subdivisions, without invoking observational input or composite stability assumptions.

### C.1 Scalar-Time Closure Arithmetic

Admissible particle modes in TSFT are labeled by integers $(n, q, h)$ satisfying the closure condition

$$3n + 2q + h \equiv 0 \pmod 6. \tag{168}$$

This relation defines the scalar-time phase closure required for coherence-stable eigenmodes. Because closure is defined modulo six, the admissible phase space is discretized into six equivalence classes.

The closure index $h$ therefore represents the residual phase class of the mode relative to the spectral and family indices.

### C.2 Charge from Closure Symmetry

Electric charge in TSFT arises from the closure index $h$. The natural charge assignment is

$$Q = \frac{h}{3}. \tag{169}$$

This identification follows from the requirement that charge be invariant under full scalar-time closure cycles. Since closure is defined modulo six, the smallest nontrivial closure increment corresponds to

$$h \to h + 1. \tag{170}$$

However, physical observables must remain invariant under full closure symmetry. Because the closure condition is modulo six, the physically distinct charge sectors correspond to equivalence classes of $h$ modulo three. Thus the observable charge is determined by

$$Q = \frac{h}{3}. \tag{171}$$

This yields the allowed charge spectrum

$$Q \in \left\{0, \pm\frac{1}{3}, \pm\frac{2}{3}, \pm 1, \dots\right\}. \tag{172}$$

This fractional charge structure arises directly from scalar-time closure symmetry.

### C.3 Minimal Observable Charge Sector

The scalar-time closure condition is defined modulo six:

$$3n + 2q + h \equiv 0 \pmod 6. \tag{173}$$

However, observable charge must remain invariant under full scalar-time phase cycles. Since a full closure corresponds to a phase rotation of $2\pi$, equivalent charge sectors are those related by closure-preserving phase shifts.

Because the closure condition is modulo six, two values of $h$ separated by three units correspond to opposite phase sectors:

$$h \to h + 3 \tag{174}$$

This transformation produces

$$Q \to Q + 1. \tag{175}$$

Thus the physically distinct charge sectors correspond to equivalence classes of $h$ modulo three.

Therefore the minimal observable fractional charge unit is

$$Q = \frac{h}{3}. \tag{176}$$

### C.4 Exclusion of Finer Fractional Charges

One may ask whether smaller fractional charges such as sixths or twelfths could arise. However, such charges would require non-integer values of the closure index $h$.

For example, a sixth-unit charge would require

$$Q = \frac{1}{6}, \tag{177}$$

which implies

$$h = \frac{1}{2}. \tag{178}$$

Since the closure index must be an integer, such fractional values are not admissible. Thus sixth-based charge units are excluded by scalar-time closure arithmetic.

Similarly, twelfth-based charges would require

$$h = \frac{1}{4}, \tag{179}$$

which again violates the integer closure condition.

Therefore, fractional charges smaller than thirds are excluded by the integer closure structure of TSFT.

### C.5 Lowest Nonzero Fractional Charge

The smallest nonzero admissible closure index is

$$h = \pm 1. \tag{180}$$

Substituting into the charge relation yields

$$Q_{\min} = \pm\frac{1}{3}. \tag{181}$$

Thus the lowest nonzero fractional charge permitted by scalar-time closure is one third.

### C.6 Result

The scalar-time closure structure therefore implies

$$Q_{\min} = \frac{1}{3}. \tag{182}$$

This result follows directly from the integer closure structure and does not rely on composite stability arguments or observational input. Fractional charges arise as closure-index sectors of scalar-time coherence, and thirds emerge as the smallest physically admissible fractional charge unit.

This provides a first-principles explanation for quark-like fractional charge within Time-

Scalar Field Theory.

# A. Appendix D: Variational Structure and Composite Selection in TSFT

## A.1 D.1 Derivation of the Scalar-Time Field Action

In Time-Scalar Field Theory, the scalar field $\Theta(x,t)$ represents the local rate of temporal evolution and therefore constitutes the fundamental dynamical degree of freedom of the theory. The dynamics of $\Theta$ must therefore satisfy several minimal structural requirements:

1. Locality — interactions depend only on the field and its derivatives
2. Lorentz compatibility — spacetime symmetry must be preserved
3. Second-order dynamics — avoiding higher derivative instabilities
4. Scalar invariance — since $\Theta$ is a scalar-time field

Under these constraints, the lowest-order effective action is uniquely determined (up to field redefinitions) as

$$S_\Theta = \int d^4x \left[ \frac{1}{2}(\partial_\mu \Theta)(\partial^\mu \Theta) - V(\Theta) \right] \tag{183}$$

This represents the minimal dynamical structure consistent with scalar-time field dynamics in TSFT.

Linearizing about a coherence-stable background:

$$\Theta = \Theta_0 + \delta\Theta \tag{184}$$

leads to the equation of motion:

$$\Box \delta\Theta + V''(\Theta_0)\delta\Theta = 0 \tag{185}$$

Defining

$$\omega_0^2 = V''(\Theta_0) \tag{186}$$

yields plane-wave solutions

$$\delta\Theta \sim e^{i(kx - \omega t)} \tag{187}$$

which produce the dispersion relation

$$\omega^2 = c^2 k^2 + \omega_0^2 \tag{188}$$

Thus, the relativistic dispersion relation follows from the minimal scalar-time dynamics.

### A.2 D.2 Coherence-Locking Operator Definition

Composite states in TSFT arise through coherence locking of constituent modes. This process is governed by a variational principle minimizing scalar-time coherence energy.

Let the composite Hilbert space be

$$\mathcal{H}_{\text{comp}} = \psi_1 \otimes \psi_2 \otimes \cdots \otimes \psi_n \tag{189}$$

Define the closure-admissible subspace

$$\mathcal{H}_{\text{closure}} \subset \mathcal{H}_{\text{comp}} \tag{190}$$

consisting of states satisfying scalar-time closure constraints.

The coherence-locking operator is defined as

$$\hat{C} = \arg \min_{\Psi \in \mathcal{H}_{\text{closure}}} E_\Theta[\Psi] \tag{191}$$

where $E_\Theta$ is the scalar-time coherence energy functional.

This operator selects the lowest-energy closure-consistent composite configuration.

### A.3 D.3 Spin Branch Selection

Consider three spin-$\frac{1}{2}$ constituents:

$$\tfrac{1}{2} \otimes \tfrac{1}{2} \otimes \tfrac{1}{2} = \tfrac{1}{2} \oplus \tfrac{1}{2} \oplus \tfrac{3}{2} \tag{192}$$

Higher total spin corresponds to increased scalar-time curvature within the composite configuration. The scalar-time energy scales as

$$E_\Theta \sim \int (\nabla \Theta)^2 d^3x \tag{193}$$

Aligned spin configurations require larger curvature gradients, increasing the coherence energy.

Therefore, coherence minimization selects the lowest-energy branch:

$$\hat{C}\left(\tfrac{1}{2}\otimes\tfrac{1}{2}\otimes\tfrac{1}{2}\right)\rightarrow\tfrac{1}{2} \tag{194}$$

Thus, spin-$\frac{1}{2}$ ground states emerge naturally.

### A.4 D.4 Explicit Closure Modes

Closure constraints require

$$3n+2q+h\equiv 0 \pmod 6 \tag{195}$$

Example closure modes:

$$(n,q,h)=(1,0,3) \tag{196}$$
$$(n,q,h)=(0,1,4) \tag{197}$$
$$(n,q,h)=(2,0,0) \tag{198}$$

These produce admissible composite configurations satisfying closure conditions.

### A.5 D.5 Phase Reduction

Closure symmetry under scalar-time evolution requires

$$e^{i2\pi(h+3)/6}=-e^{i2\pi h/6} \tag{199}$$

Since physical observables depend on bilinear combinations, overall phase sign is unobservable. Thus,

$$h \mod 6\rightarrow h \mod 3 \tag{200}$$

This yields charge quantization in thirds.

### A.6 D.6 Summary

Appendix D establishes:

- Minimal scalar-time action
- Dispersion relation derivation

- Coherence-locking operator definition
- Spin branch selection
- Closure mode existence
- Charge quantization reduction

These results complete the variational structure of composite formation in TSFT.

# B. Proton and Neutron Analogues in Time-Scalar Field Theory

This appendix outlines the emergence of proton-like and neutron-like composite states within the Time-Scalar Field Theory (TSFT) framework. The goal is not to force identification with Standard Model particles, but to demonstrate that TSFT naturally produces composite fermionic states with properties structurally consistent with nucleons.

## B.1 Three-Fermion Composite Structure

From Appendix B, closure-stable composite fermionic states arise from three coherence-stable fermionic eigenmodes:

$$\Psi_{\text{comp}} = \hat{C}(\psi_1 \otimes \psi_2 \otimes \psi_3) \tag{201}$$

where $\hat{C}$ denotes the coherence-locking operator selecting closure-preserving configurations.

Each constituent satisfies the scalar-time closure condition:

$$3n_i + 2q_i + h_i \equiv 0 \pmod 6 \tag{202}$$

The composite state therefore satisfies:

$$\sum_i (3n_i + 2q_i + h_i) \equiv 0 \pmod 6 \tag{203}$$

ensuring composite coherence stability.

## B.2 Charge Structure of Composite States

From Appendix C, fractional charges arise naturally from the closure index:

$$Q_i = \frac{h_i}{3} \tag{204}$$

Composite charge is additive:

$$Q_{\text{comp}} = \sum_i Q_i \tag{205}$$

This immediately allows construction of two lowest-order composite states:

### B.3 Proton-like State

Consider three fermionic constituents with charges:

$$\left(+\frac{2}{3}, +\frac{2}{3}, -\frac{1}{3}\right) \tag{206}$$

The composite charge becomes:

$$Q_p = \frac{2}{3} + \frac{2}{3} - \frac{1}{3} = +1 \tag{207}$$

This defines a positively charged, three-fermion composite:

$$\Psi_p = \hat{C}(\psi_{2/3} \otimes \psi_{2/3} \otimes \psi_{-1/3}) \tag{208}$$

This state is structurally analogous to a proton.

### B.4 Neutron-like State

Similarly, a neutral three-fermion composite arises from:

$$\left(+\frac{2}{3}, -\frac{1}{3}, -\frac{1}{3}\right) \tag{209}$$

Yielding:

$$Q_n = \frac{2}{3} - \frac{1}{3} - \frac{1}{3} = 0 \tag{210}$$

This defines a neutral composite:

$$\Psi_n = \hat{C}(\psi_{2/3} \otimes \psi_{-1/3} \otimes \psi_{-1/3}) \tag{211}$$

This state is structurally analogous to a neutron.

### B.5 Spin Structure

From spin composition rules, three spin-$\frac{1}{2}$ fermions combine as:

$$\frac{1}{2} \otimes \frac{1}{2} \otimes \frac{1}{2} = \frac{1}{2} \oplus \frac{1}{2} \oplus \frac{3}{2} \tag{212}$$

Coherence-locking selects the lowest-energy closure-preserving branch, yielding spin-$\frac{1}{2}$ composite ground states:

$$S_p = S_n = \frac{1}{2} \tag{213}$$

consistent with nucleon spin structure.

### B.6 Mass Near-Degeneracy

The two composite states differ only by internal constituent arrangement:

$$\Psi_p = (2/3, 2/3, -1/3) \tag{214}$$

$$\Psi_n = (2/3, -1/3, -1/3) \tag{215}$$

Because the total coherence structure is similar, TSFT predicts near-degenerate composite masses:

$$M_p \approx M_n \tag{216}$$

Small mass splitting arises from asymmetry in internal coherence gradients:

$$\Delta M \sim \delta\rho_{\text{comp}} \tag{217}$$

This qualitatively matches the observed proton-neutron mass splitting.

### B.7 Interpretation

These results demonstrate that TSFT naturally produces:

- Three-fermion composite states
- Fractional constituent charges
- Integer composite charges

- Spin-$\frac{1}{2}$ ground states
- Near-degenerate composite masses

These properties emerge directly from scalar-time coherence dynamics, without externally imposed gauge structure or quark postulates.

This suggests that proton-like and neutron-like composite states arise naturally within the TSFT framework.

Importantly, this identification is structural rather than exact. A full quantitative mapping to Standard Model nucleons requires computation of composite mass spectra and interaction strengths, which is left to future work.

Nevertheless, the emergence of nucleon-like states from scalar-time coherence represents a significant structural validation of TSFT.

# C. Appendix F: Emergent Confinement from Scalar-Time Coherence

In this appendix we derive confinement-like behavior from scalar-time coherence dynamics without assuming flux-tube formation.

## C.1 Scalar-Time Coherence Energy Functional

Consider the scalar-time deformation field $a_\mu$ with action

$$S_a = \int d^4x \left[ \frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \frac{M_a^2}{2} a_\mu a^\mu + \lambda (a_\mu a^\mu)^2 - J_\mu a^\mu \right]. \tag{218}$$

The corresponding energy functional is

$$E[a] = \int d^3x \left[ \frac{1}{2} (\nabla a)^2 + \frac{M_a^2}{2} a^2 + \lambda a^4 - J a \right]. \tag{219}$$

## C.2 Separated Sources

Consider two separated sources

$$J(x) = J_1(x) + J_2(x) \tag{220}$$

with separation $r$.

The total energy becomes

$$E[r] = E_{\text{self}} + E_{\text{interaction}}. \tag{221}$$

### C.3 Energy Minimization

To minimize energy, the field must distribute such that

$$\delta E = 0 \tag{222}$$

which yields

$$\nabla^2 a - M_a^2 a - 4\lambda a^3 = -J. \tag{223}$$

For large separation, the nonlinear term dominates,

$$4\lambda a^3 \sim J. \tag{224}$$

This drives localization of the field along the minimal-energy configuration connecting sources.

### C.4 Emergent String Geometry

Energy minimization favors configurations that minimize transverse area while maintaining longitudinal continuity.

The minimal-energy solution therefore satisfies

$$a(x) \to a_{\text{tube}}(x_\parallel) \tag{225}$$

with transverse localization.

Thus scalar-time coherence forms a flux-tube-like configuration as a consequence of energy minimization.

### C.5 Linear Potential

The energy stored in the tube is

$$E(r) = \sigma r \tag{226}$$

where

$$\sigma = \int d^2x_\perp \left[\frac{1}{2}(\nabla a)^2 + \lambda a^4\right]. \tag{227}$$

Thus the interaction potential becomes

$$V(r) = \sigma r. \tag{228}$$

This behavior is analogous to flux-tube formation in non-Abelian gauge theories, but arises here from nonlinear scalar-time coherence dynamics rather than gauge-field self-interaction.

This produces confinement-like behavior within scalar-time dynamics.

### C.6 Nuclear Size Scaling

The short-range nature of the residual scalar-time interaction implies saturation of binding beyond nearest neighbors. Consequently, nucleons pack into approximately constant-density configurations.

If each nucleon occupies an effective coherence volume $V_0$, then for a nucleus containing $A$ nucleons,

$$V \sim AV_0.$$

Assuming approximately spherical geometry, the nuclear radius satisfies

$$V = \frac{4}{3}\pi R^3 \sim AV_0,$$

yielding

$$R \sim A^{1/3}.$$

Thus, the empirically observed nuclear size scaling emerges naturally from scalar-time coherence packing and short-range residual interaction saturation. This provides an additional structural prediction of Time-Scalar Field Theory at the nuclear scale.