

# Electric Charge as an Emergent Noether Current—Quantization Linked to Planck’s Constant

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## Abstract

We propose a field-based framework in which fermions are represented as bound configurations of two coupled real fields (“germions”) in ordinary 3 + 1 spacetime. In this approach, electric charge emerges dynamically as a conserved Noether current generated by the internal rotation of the coupled fields. Charge quantization follows from the compactness of the internal phase and is directly tied to Planck’s constant through the relation  $Q = n\hbar/\kappa = ne$ , where  $\kappa = \hbar/e$  defines the universal scale connecting charge and action. Thus, electric charge is not a fundamental input but an emergent quantity rooted in the same oscillatory structure that gives rise to quantized energy. The framework yields concrete experimental benchmarks: a finite effective electron radius  $r_e \approx 2 \times 10^{-20}$  m ( $\Lambda = 10$  TeV), deviations in Bhabha scattering cross sections ( $\frac{\delta\sigma}{\sigma} \approx 1.7 \times 10^{-3}$  at  $\sqrt{s} = 1$  TeV), and a predicted anomalous magnetic moment shift ( $\delta a_e \sim 10^{-15}$ ). These effects provide clear distinctions from the Standard Model, where the electron is point like and charge is postulated rather than derived. By linking charge quantization directly to Planck’s constant, the coupled-fields model offers both a conceptual reinterpretation of one of nature’s most fundamental constants and a set of measurable predictions.

## Keywords

Real Coupled-Fields, Fermions, Germions, Electric Charge, Planck Constant, Charge Quantization

## 1. Introduction

Electric charge is one of the most fundamental and precisely conserved quantities

in physics. In the standard quantum framework it is treated as an intrinsic attribute of matter—assigned to particles but never truly explained. The origin of charge, the reason for its discrete values, and its possible connection to internal particle structure remain unresolved.

In this work, we approach the problem from a different perspective. Building on the coupled real-field model (CF) of fermions (a couple of germions) [1]-[4], we propose that charge is not a primary input but rather an emergent property. A fermion—such as the electron—is modeled not as a point like particle, but as a composite configuration of two coupled real germions in ordinary spacetime. Within this framework, the mutual rotation of the coupled fields generates a conserved Noether current that is identified with electric charge.

This viewpoint offers several advantages. First, charge quantization arises naturally from the compact internal phase of the fields, eliminating the need to impose it by hand. Second, charge conservation becomes a direct consequence of underlying rotational symmetry. Third, gauge invariance ensures consistent coupling to the electromagnetic field, unifying charge dynamics with established field-theoretic principles.

The central question guiding this work is: **How does electric charge emerge from the internal dynamics of coupled fields?** By addressing this, we not only provide a physical origin for one of nature's most essential constants, but also uncover testable implications—ranging from finite-size effects of the electron to measurable deviations in scattering cross sections and magnetic moment corrections.

In what follows, we develop the theoretical framework, derive the charge-energy relations, and compare predictions of the coupled-strings model with those of the Standard Model. The results point toward a reinterpretation of charge as a manifestation of internal field dynamics rather than as an unexplained fundamental label.

In this picture, electric charge is no longer a fundamental label assigned to particles, but a quantitative measure of internal rotational symmetry in a compact field space.

## 2. Electric Charge as a Topological or Geometric Property

One possibility is that the electric charge originates from the **topological configuration** of the coupled germions. Consider a pair of strings or real fields, interacting in a closed configuration. The relative winding number, helicity, or phase twist between the two fields may give rise to an emergent quantity that behaves like electric charge.

This geometric interpretation provides a natural explanation for the **quantization of charge**. If only certain topological configurations are stable or allowed (similar to quantized magnetic flux in superconductors), then only specific values of charge can emerge—such as,  $\mp e$ .

Electric charge  $Q$  in field theory is tied directly to an internal symmetry—typi-

cally a U(1) symmetry—via Noether’s theorem. If a Lagrangian is invariant under a continuous phase rotation of a field, a conserved current  $j^\mu$  and a conserved charge  $Q$  arise.

### 3. Charge in the Coupled-String Fermion Model

In our model, a fermion is composed of coupled real two interacting string-like fields (germions):

Each germion satisfies a classical field equation, and the interaction term between them generates both spin and charge:

$$1) \quad \mathcal{L} = \frac{1}{2}(\partial_\mu \phi_1)^2 + \frac{1}{2}(\partial_\mu \phi_2)^2 - V(\phi_1, \phi_2)$$

#### Origin and Quantization of Charge

Charge is derived from a Noether current associated with the internal field symmetry:

Let us define a pseudo-U(1) transformation:

$$\phi_1 \rightarrow \phi_1 + \varepsilon \phi_2 \quad (1)$$

$$\phi_2 \rightarrow \phi_2 - \varepsilon \phi_1 \quad (2)$$

This leads to a conserved current:

$$2) \quad J_\mu = \phi_1 \partial_\mu \phi_2 - \phi_2 \partial_\mu \phi_1$$

And the associated charge:

$$Q = \int d^3x J^0 = \int d^3x \left( \phi_1 \frac{\partial \phi_2}{\partial t} - \phi_2 \frac{\partial \phi_1}{\partial t} \right) \quad (3)$$

This expression shows that charge arises dynamically from the rotational coupling of the two fields in configuration space.

If we define the vector  $\Phi = (\phi_1, \phi_2)$  then  $Q = \int d^3x (\Phi \times \partial \Phi / \partial t)$ , which shows the connection between charge and rotational coupling.

**When does the Noether charge exist?** The current  $J_\mu = \phi_1 \partial_\mu \phi_2 - \phi_2 \partial_\mu \phi_1$  is conserved only if the Lagrangian has the global SO(2) symmetry—*i.e.*,  $V = V(\phi_1^2 + \phi_2^2)$ . Without it, the “emergent charge from rotation” is not guaranteed to be conserved.

#### Charge and Electromagnetic Coupling

The above Lagrangian lacks gauge invariance. To make it gauge invariant one must add a gauge field  $A_\mu$  and replace  $\partial_\mu \rightarrow \partial_\mu - iqA_\mu$ . This is called a local gauge transformation.

Gauge invariance is a demand which expresses local U(1) invariance in the internal two-field space  $(\phi_1, \phi_2)$ .

In other words, our physical equations must remain invariant under a U(1) transformation  $\varphi \rightarrow e^{iq\alpha(x)}\varphi$  of the fields, for an arbitrary  $\alpha(x)$ .

Gauge invariance is implemented via covariant derivatives and addition of a gauge field  $A_\mu$ , to ensure a well-defined, conserved electric charge and consistent coupling to  $A_\mu$ .

## 4. Gauge-Invariant Lagrangian for Well-Defined Electric Charge

This section explains the correct gauge-invariant Lagrangian for a theory where electric charge is well-defined and conserved. Electric charge conservation arises from local U(1) gauge invariance, not from explicit symmetry-breaking terms.

Namely, we require  $\mathcal{L}$  to be invariant under  $\varphi \rightarrow e^{iq\alpha(x)}\varphi$ .

But this requires the introduction of an external gauge field,  $A_\mu$ , which interacts with the fields via the coupling constant  $q$ .

For a complex scalar field  $\varphi$  carrying electric charge  $q$ , the minimal gauge-invariant Lagrangian is:

$$\mathcal{L} = (D_\mu\varphi)(D_\mu\varphi) - V(|\varphi|^2) - 1/4 F_{\mu\nu}F^{\mu\nu} \quad (4)$$

Here, the covariant derivative and field strength tensor are defined as:

$$D_\mu = \partial_\mu + iqA_\mu \quad (5)$$

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu \quad (6)$$

This Lagrangian is invariant under the local U(1) gauge transformation:

$$3) \quad \varphi \rightarrow e^{iq\alpha(x)}\varphi$$

$$4) \quad A_\mu \rightarrow A_\mu - \partial_\mu\alpha(x)$$

Since in our model, there are two real fields  $\phi_1$  and  $\phi_2$ , we need to modify our covariant derivatives as follows.

$$5) \quad D_\mu\phi_1 = \partial_\mu\phi_1 - qA_\mu\phi_2$$

$$6) \quad D_\mu\phi_2 = \partial_\mu\phi_2 + qA_\mu\phi_1$$

This is evident if we define  $\phi = \phi_1 + i\phi_2$  and insert in  $D_\mu\phi = \partial_\mu\phi + iqA_\mu\phi$ . The above covariant derivatives create a mixture of  $\phi_1$  and  $\phi_2$ .

## 5. From Global to Local (Gauge) Symmetry

When the internal SO(2) symmetry is promoted from a global to a local symmetry, the phase angle  $\theta$  becomes spacetime-dependent,  $\theta \rightarrow \theta(x)$ . Ordinary derivatives no longer transform covariantly under such local rotations, producing additional terms proportional to  $\partial_\mu\theta$ . To preserve invariance of the action, a new compensating field  $A_\mu$  must be introduced. This field transforms in such a way as to cancel the non-covariant pieces, ensuring that derivatives remain tangent to the internal symmetry manifold. The resulting covariant derivative defines a gauge connection, and its dynamics naturally reproduce electromagnetism. Thus, the electromagnetic field arises as the geometric response required to maintain local internal symmetry. Promoting the internal symmetry from a global to a local one introduces a gauge connection and the usual minimal coupling. The associated Noether current is precisely the electric current.

$$D_\mu = \partial_\mu - iqA_\mu$$

## 6. Noether Current

The conserved Noether current associated with this symmetry corresponds to the electric current.

$$J^\mu = \bar{\Psi} \gamma^\mu \Psi$$

### Examples match observation

Electron: nontrivial representation  $\rightarrow -e$ .

Neutrino: trivial representation  $\rightarrow 0$ .

Quarks: nontrivial representations in sectors with  $2\pi/3$  periodicity  $\rightarrow \pm 1/3, \pm 2/3$ .

### Bottom line

All fermions are paired, but only some are charged. Charge emerges from the symmetry class of the coupling (*i.e.*, the relative phase structure), not from the mere fact of being a two-germion composite.

## 7. Gauge-Invariant Electric Current

The electric current derived from the gauge-invariant Lagrangian is:

$$j_\mu = iq(\varphi D_\mu \varphi - (D_\mu \varphi)\varphi) \quad (7)$$

7) Noether current derived from SO(2) symmetry.

In polar field variables  $\varphi = \rho e^{i\theta}$ , ( $\phi_1, \phi_2 \rightarrow \rho, \theta$ ) where  $\rho = \sqrt{\phi_1^2 + \phi_2^2}$  and  $\theta = \tan^{-1}\left(\frac{\phi_1}{\phi_2}\right)$  the charge density takes the form:

$$j_0 = q\rho^2(\partial_t \theta - qA_0) \quad (8)$$

This expression shows that a nonzero electric charge density can arise from a time-dependent internal phase  $\theta$  or from the presence of an electric potential  $A^0$ . The local U(1) gauge invariance ensures that electric charge is well-defined and conserved.

The internal phase  $\theta$  is defined as an angular coordinate on the compact manifold  $S^1$ . By construction,  $\theta \equiv \theta + 2\pi$ , identifying all points modulo  $2\pi$ . This compact topology enforces periodic boundary conditions, and therefore quantizes the conjugate momentum associated with  $\theta$ . This explains why the electric charge, derived from the canonical momentum of  $\theta$ , takes discrete values. The compactness is not imposed ad hoc, but follows from the geometry of the two-field configuration.

In our model,  $\phi_1 = A \sin(\omega t)$  and  $\phi_2 = A \cos(\omega t)$  and the charge density becomes

$$j_0 = qA^2\omega - q^2 A^2 A_0 \quad (9)$$

Which can be safely approximated to ( $\omega \gg qA_0$ )

$$1) \quad j_0 = qA^2\omega$$

And integrating over a volume  $V$

$$2) \quad Q = \int_V j_0 d^3x = qA^2V\omega$$

**Under normalization (since**  $A^2V\omega$  has dimensions of volume,  $A^2\omega$  is dimensionless and  $q$  has the dimensions of charge density. One may therefore write: (describes charge in terms of internal rotation frequency and amplitude)

$$Q = qA^2\omega \quad (10)$$

The compact rotor degree of freedom also admits a natural double-cover property analogous to spin-1/2 systems. Under a  $2\pi$  rotation, the internal configuration acquires a sign reversal, while only after a  $4\pi$  rotation does the state return to its original physical configuration. This behavior is characteristic of SU(2), the double cover of SO(3), and emerges here from continuity of the internal germion configuration. Thus, the spinor nature of fermions is encoded in the topology of the coupled fields, rather than being postulated.

The interaction of a charged fermion with an electromagnetic gauge field  $A_\mu$  is mediated by the current  $J^\mu$ :

$$\mathcal{L}_{int} = -eA_\mu J^\mu \quad (11)$$

Since  $J^\mu$  depends on both  $\phi_1$  and  $\phi_2$ , the entire interaction depends on internal field dynamics, not on a particle's trajectory or position alone.

## 8. Step-by-Step: Why Paired Germions Don't Force Electric Charge

### Start from the structure

Every fermion is built from two coupled germions (real strings/fields). The pairing gives universal internal dynamics (e.g., spin), but says nothing yet about electric charge.

## 9. Separate Global vs. Relative Phase

The pair has a global phase (physically irrelevant) and a relative phase between the two germions. Only this relative phase can create observable internal effects.

Pairing alone does not guarantee electric charge. Only when the relative phase between germions transforms nontrivially under SO(2) does a nonzero Noether current result. Configurations that transform trivially produce perfectly canceling internal currents, yielding electrically neutral fermions while still retaining spin-1/2 structure. Thus, charge is not a necessary consequence of compositeness but of symmetry representation.

Define the relative phase between the two germions:

$$\Delta\varphi = \varphi_1 - \varphi_2 \quad (12)$$

## 10. Identify the Internal Symmetry

Rotating the pair's internal state by a common angle in the germion space acts like an internal U(1) symmetry.

Explicitly show the internal U(1) symmetry transformation:

$$\Psi \rightarrow e^{i\alpha} \Psi. \quad (13)$$

### Define charge as a symmetry label

Electric charge is the label of how the coupled pair transforms under the internal U(1) symmetry—*i.e.*, which representation the state occupies.

## 11. When Charge Appears

If the coupled state takes a nontrivial U(1) representation, its internal currents do not cancel, and an external electromagnetic field couples to it. That state is charged.

## 12. When Does Neutrality Appear

If the relative phase/configuration is such that internal currents cancel exactly, the state transforms trivially under U(1). No external EM coupling appears. The fermion is neutral—yet it still has spin and all the other pairing-induced properties. For instance, when ( $\omega \approx qA_0$ )

## 13. Signs and Magnitudes of Charge

The orientation of the internal rotation sets the sign (e.g.,  $+e$  vs.  $-e$ ). The allowed phase classes (set by boundary conditions/topology of the pair) fix the magnitude. Different periodicities can yield integer or fractional units.

$$q = n \cdot e/3, \quad n \in \{-2, -1, 0, 1, 2\}$$

## 14. Comparison with Standard Quantum Theory (Table 1)

**Table 1.** Comparison between Standard Model and CF Model.

Feature	Standard QM	Coupled string model
Origin of charge	Postulated	Emergent from field coupling
Charge quantization	Imposed via group theory	Natural from discrete field dynamics
Charge conservation	Global U(1) symmetry	Noether current from internal field rotation
Effect of decomposition	Charge remains with each particle	The <i>mechanism</i> for generating $\mathcal{J}^\mu$ via mutual rotation (the particular <i>dynamical mechanism</i> through mutual rotation) disappears if inter-field coupling is broken, although a global SO(2) symmetry would still support a conserved Noether charge.
Charge distribution	Point like (Dirac delta)	Extended, field-distributed
Coupling to $A_\mu$	Via minimal substitution	Via dynamical current coupling

**Table 1:** Comparison between the Standard Model and the coupled-fields model in their treatment of electric charge. Unlike the SM, which postulates charge

as an intrinsic property of point like particles, the coupled-fields model derives charge dynamically from internal rotations, ensuring natural quantization, gauge-invariant conservation, and extended charge structure. Energy–Charge Relationship in the Coupled-Strings Model.

In the coupled-strings model, a fermion consists of two orthogonal real-valued fields that oscillate in a phase-shifted manner, forming a rotating vector in an internal 2D field space. The rotation generates a conserved current, interpreted as electric charge  $Q$ , while the internal oscillation stores energy  $E$ . The relationship between  $E$  and  $Q$  follows from Noether's theorem and the field dynamics.

#### Two Coupled Real Fields

The two orthogonal components of the fermion's internal field can be expressed as:

$$\varphi^1 = A \cos(\omega t) \quad (14)$$

$$\varphi_2 = A \sin(\omega t) \quad (15)$$

These form a rotating vector in the internal 2D field space, with rotation frequency  $\omega$  setting the internal current. We consider this mode to be the fundamental mode of least energy, and with opposite phase in order to preserve momentum.

#### Charge from Field Current

From Noether's theorem applied to the internal U(1)-like rotation, the conserved charge is proportional to the current density  $j^0$ :

$$Q \propto \omega A^2 \quad (16)$$

Thus, electric charge is proportional to the rotation frequency and the square of the amplitude.

#### Energy of the Internal Oscillation

The internal oscillation stores field energy:

$$E_{int} \propto \frac{1}{2} m_{eff} \omega^2 A^2 \quad \text{Energy stored in internal oscillations.} \quad (17)$$

where  $m_{eff}$  is the effective inertia of the field.

#### Eliminating $A^2$

From the charge formula:

$$A^2 \propto Q/\omega \quad (18)$$

Substituting into the energy formula:

$$E_{int} \propto \frac{1}{2} m_{eff} \omega^2 (Q/\omega) = \frac{1}{2} m_{eff} \omega Q \quad (19)$$

Therefore, in the coupled-strings model:

$$E \propto \omega Q \quad (20)$$

If  $\omega$  is fixed (a fundamental mode),  $Q$  is constant, explaining why real particles have fixed charge magnitude.

## 15. Detailed Derivations: Charge-Energy Relations in the Coupled-Strings Model

We represent two real fields in polar variables:

$$(\varphi^1, \varphi^2) = A(x)(\cos \theta(x), \sin \theta(x)) \quad (21)$$

For a rigid rotor mode:

$$A(x, t) = A_0 f(x), \quad \theta(x, t) = \theta(t) \quad (22)$$

Normalization:  $\int d^3x f^2(x) = 1$ , hence  $I \equiv \int d^3x A^2 = A_0^2$ .

This normalization does not reduce physical generality. It is equivalent to mode normalization in quantum field theory, where spatial profiles of field modes are normalized to unity while retaining all physical information in amplitudes and phases. Observables such as charge and energy remain invariant under such rescaling.

Define angular velocity  $\omega \equiv \dot{\theta}$ .

Including the  $\kappa$ -Term

Extended Lagrangian:

$$\mathcal{L} = \frac{1}{2} I \omega^2 + \kappa I \omega \quad (23)$$

Conserved charge:

$$Q_{rot} = I(\omega + \kappa) \quad (24)$$

Hamiltonian:

$$E_{rot} = \frac{1}{2} I \omega^2 \quad (25)$$

Eliminating I:

$$E_{rot} = Q_{rot}^2 / (2I) - \kappa Q_{rot} + \frac{1}{2} \kappa^2 I \quad (26)$$

Quantized spectrum:

$$E_n = (n\hbar - \kappa I)^2 / (2I) + const. \quad (27)$$

## 16. Gauge Coupling to Electromagnetism

With local U(1),  $D_0 \theta = \dot{\theta} - (e/\hbar) A_0$ .

Rotor momentum:

$$p^\theta = I D_0 \theta + \kappa I = Q_{rot} \quad (28)$$

Electromagnetic charge:

$$Q_{EM} = (e/\hbar) Q_{rot} \quad (29)$$

Hence quantization:

$$Q_{EM} = ne \quad (30)$$

Energy-Charge Proportionality

From elimination:

$$E_{rot} = \frac{1}{2} \omega \quad (31)$$

Phenomenological form:

$$E = \kappa_E Q \omega Q_{rot} \quad (32)$$

Thus:

$$Q_{rot} = \frac{n\hbar}{\kappa_E Q} \quad (33)$$

## 17. Relationship between Electric Charge $Q$ , Planck's Constant $h$ , and Coupling $k$

This document explains the relationship between the electric charge  $Q$ , Planck's constant  $h$ , and the coupling constant in the context of the coupled-strings fermion model. In this model, fermions are composed of two real-valued coupled fields whose oscillations give rise to intrinsic properties such as mass, spin, and charge.

### Fundamental Frequency and Quantization

In quantum theory, by quantizing the internal rotational mode the energy of a fundamental mode is given by the relation:

$$E = nh\omega \quad (34)$$

where  $E$  is the quantized energy,  $h$  is Planck's constant,  $\omega$  is the angular frequency, and  $n$  is an integer quantum number.

### Electric Charge Relation

In the coupled-strings approach, the electric charge  $Q$  can be expressed analogously to energy:

$$Q = nh'\omega \quad (35)$$

Here  $h'$  is a constant with dimensions of charge-time, analogous to Planck's constant for charge. In many physical scenarios,  $h'$  can be proportional to  $h$ , linking charge quantization to the same underlying oscillatory structure.

### Ratio Between Charge and Energy Constants

If we compare the two expressions for  $E$  and  $Q$ , we find:

$$\frac{Q}{E} = \frac{h'}{h} \quad (36)$$

This ratio is independent of frequency  $\omega$  and of the quantum number  $n$ , indicating that the proportionality between charge and energy in this model is a fixed constant determined by the nature of the coupling between the two strings.

### Coupling Constant Connection

The coupling constant  $k$  in this model characterizes the strength of the interaction between the two real fields. A stronger coupling implies a higher induced circulating field current, hence a larger effective charge  $Q$  for the same oscillation energy  $E$ .

In simplified form, one can write:  $Q \propto k \cdot h$

This implies that the observed quantization of charge may emerge from a combination of the universal Planck constant  $h$  and a coupling factor  $k$  determined by the internal string dynamics.

#### Physical Interpretation

From this perspective, Planck's constant  $h$  sets the scale for quantization in both energy and charge domains. The electric charge of a particle is then not an independent fundamental constant, but an emergent property resulting from the same oscillatory structure that gives rise to quantized energy, modulated by the coupling  $k$ .

## 18. Coupled Strings and Planck's Constant

From the model as described in [1]-[4], we found that the coupled real wave functions  $\varphi_1$  and  $\varphi_2$  can be modeled using string-like dynamics. When the coupling force between these strings is proportional to their tension  $\tau$  and displacement, we derive the relation:

$$\tau = \hbar \cdot k \quad (37)$$

This equation reveals a physical interpretation of the Planck constant  $\hbar$ : it is the proportionality constant between the internal coupling of the two fields, and their induced internal tension  $\tau$ . This fundamentally reinterprets  $\hbar$  as a property emerging from the geometry and dynamics of real fields.

Assuming the coupling arises from an exchange of massless quanta, we can depict the total internal exchange between two strings as giving rise to a finite tension field. This tension resists separation, effectively confining the two strings into a single fermionic particle, such as an electron.

$$\tau \propto \{\text{Exchange}\} \rightarrow \tau = \hbar \cdot \{\text{Exchange Rate}\} \rightarrow \tau = \hbar \cdot k$$

In other words, our model predicts that the charge  $Q$  is proportional to the exchange rate and to Planck's constant.

#### Binding Exchange Mass in the Coupled-Strings Model

This document summarizes the connection between the previously derived constant  $\kappa = \hbar/e$  in the coupled-strings model and the estimated mass of the internal binding exchange particle.

#### Known Constants

**Table 2.** Known constants.

$\hbar$	$1.0546 \times 10^{-34}$ J·s
$e$	$1.6022 \times 10^{-19}$ C
$m_e c^2$	$0.511$ MeV = $8.187 \times 10^{-14}$ J
$c$	$2.998 \times 10^8$ m/s

From known values (**Table 2**) we derive:  $\kappa = \hbar/e = 6.5822 \times 10^{-16}$  V·s.

## 19. Binding Models for Different Scenarios

### A) Spring-like binding

If the two strings are bound by an effective stiffness  $K$  and effective inertia  $\mu_{\text{eff}}$ , the exchange boson mass is given by:  $m_{\text{exch}} = \hbar\omega/c^2$ , where  $\omega = \sqrt{K/\mu_{\text{eff}}}$ .

Using the electron as the reference fermion ( $m_f = m_e$ ) and  $\kappa = \hbar/e$  ( $\kappa \equiv \hbar/e$  as a *constant with units of Weber*) if  $\omega$  is comparable to the Compton frequency  $\omega_c = m_e c^2 / \hbar \approx 7.763 \times 10^{20} \text{ s}^{-1}$ , then  $m_{\text{exch}} \approx m_e \approx 0.511 \text{ MeV}/c^2$ .

### B) Yukawa-type range estimate

A Yukawa potential is

$$V(r) = -g^2 \frac{e^{-\mu r}}{4\pi r} \quad (38)$$

where  $r$  is the distance and  $g$  a coupling constant (interaction strength).  $g =$  dimensionless gauge coupling.  $K =$  mechanical stiffness.

If the exchange has a finite range  $R$ , then  $m_{\text{exch}} \approx \hbar/(cR)$  (see **Table 3**).

Example values:

- $R = 1 \text{ fm} \rightarrow m_{\text{exch}} \approx 200 \text{ MeV}/c^2$  (pion scale).
- $R = 10^{-18} \text{ m} \rightarrow m_{\text{exch}} \approx 200 \text{ GeV}/c^2$  (weak scale).
- $R \rightarrow \infty \rightarrow m_{\text{exch}} \rightarrow 0$  (massless).

### C) Relation to $\kappa$

$$E = \hbar\omega n; Q = ne$$

For the electron ( $n = 1$ ,  $Q = e$ ),  $\kappa = \hbar/e$ .

In the spring model,  $Q \propto E$  so a larger  $\kappa$  (weaker electric coupling) gives a lighter exchange boson.

**Table 3.** Masses of the internal exchange mediator CF model.

Scenario	Parameter	$m_{\text{exch}}$ (approx.)
Strong binding ( $\omega = \omega_c$ )	$f = 1$	$0.511 \text{ MeV}/c^2$
Finite range $R = 1 \text{ fm}$	Yukawa	$200 \text{ MeV}/c^2$

**Table 3:** Estimated masses of the internal exchange mediator in the coupled-fields model under different binding scenarios. A spring-like model gives a value near the electron mass, while Yukawa-type finite-range bindings yield mediator masses from the hadronic ( $\sim 200 \text{ MeV}$ ) to electroweak ( $\sim 200 \text{ GeV}$ ) scale. These scenarios highlight how the constant  $\kappa = \hbar/e$  links charge quantization to possible binding dynamics.

### Interpretation

The constant  $\kappa = \hbar/e$  fixes the proportionality between charge and action. The binding-exchange mass is not uniquely fixed by  $\kappa$  alone—it also depends on the mechanical stiffness or the range of the binding interaction. A stiffer or shorter-range binding yields a heavier exchange boson, while a softer or long-range binding yields a lighter or massless mediator.

Constraints from electroweak precision tests require that any vector mediator mixing with the photon occupy a mass range above  $\gtrsim 1$  TeV, consistent with the compositeness scales considered here. Scalar mediators coupled only to amplitude fluctuations are more weakly constrained but would still manifest as modifications of the electron's polarizability. These bounds place the coupled-fields dynamics safely within the experimentally allowed window.

## 20. Quantization of Charge and Nature of the Binding Exchange Boson

This section expands the coupled real-field model of fermions by providing explicit derivations for two key elements:

- (A) the quantization of electric charge  $Q$ , and
- (B) the identification of a possible binding exchange boson responsible for confining the coupled fields.

Quantization of  $Q$  from the Compact Internal Phase

We parametrize the two real fields as  $(\varphi_1, \varphi_2) = A(\cos \theta, \sin \theta)$ . The  $O(2)$ -invariant kinetic term becomes:

$$\mathcal{L}_0 = \frac{1}{2}(\partial_\mu A)^2 + \frac{1}{2}A^2(\partial_\mu \theta)^2 - V(A^2) \quad (39)$$

Adding the first-order coupling (the  $\kappa$ -term):

$$\mathcal{L}_\kappa = \kappa(\varphi_1 \partial_t \varphi_2 - \varphi_2 \partial_t \varphi_1) = \kappa A^2 \dot{\theta} \quad (40)$$

Thus, the effective Lagrangian reads:

$$\mathcal{L} = \frac{1}{2}(\partial_\mu A)^2 + \frac{1}{2}A^2(\partial_\mu \theta)^2 - V(A^2) + \kappa A^2 \dot{\theta}. \quad (41)$$

The conserved Noether current associated with  $\theta \rightarrow \theta + \alpha$  is:

$$j^0 = A^2 \dot{\theta} + \kappa A^2, \quad \vec{J} = A^2 \nabla \theta \quad (42)$$

Total charge:

$$Q = \int d^3x A^2 (\dot{\theta} + \kappa) = I (\dot{\theta} + \kappa), \quad \text{where } I \equiv \int d^3x A^2 \quad (43)$$

For the zero-mode, the effective degree of freedom is  $\theta(t)$  with canonical momentum:

$$\Pi^\theta = I \dot{\theta} + \kappa I = Q. \quad (44)$$

Because  $\theta$  is compact ( $\theta \equiv \theta + 2\pi$ ), quantization requires:

$$\Pi^\theta \psi_n = n \hbar \psi_n, \quad n \in \mathbb{Z}. \quad (45)$$

Hence Implementing local  $U(1)$  gauge invariance requires the substitution

$$Q = n \hbar / \kappa = ne \quad (46)$$

$$\partial_\mu \theta \rightarrow D_\mu \theta = \partial_\mu \theta - (e/\hbar) A_\mu. \quad (47)$$

The physical electromagnetic charge is then:

$$Q_{phys} = (e/\hbar) \Pi^\theta = ne. \quad (48)$$

Thus, charge quantization emerges automatically from compactness of  $\theta$  and minimal coupling.

## 21. Neutrality Condition in the Coupled-Strings Model

This presents the neutrality condition in the coupled-strings model. Below is a compact formulation that makes the statement “charge vanishes when  $q\omega = A_0$ ”, precise and gauge-invariant.

### Fields and Notation

We define:

$$\begin{aligned}\psi &= Re^{i\theta} \\ \theta &\equiv q \cdot \varphi, \quad \omega \equiv \partial^0 \varphi \\ \partial_0 \theta &= q\omega\end{aligned}$$

Electromagnetic potential:

$$A_\mu = (A_0, \vec{A})$$

Lagrangian

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} + \partial_\mu R \partial^\mu R + R^2 (\partial_\mu \theta - A_\mu) (\partial^\mu \theta - A^\mu) - V(R)$$

Euler–Lagrange Equations

From variation of the action:

- 1)  $\partial_\nu F^{\nu\mu} = 2R^2 (A^\mu - \partial^\mu \theta) \equiv J_{em}^\mu$  Maxwell with matter source.
- 2)  $\partial_\mu [R^2 (\partial^\mu \theta - A^\mu)] = 0$  Phase (Noether) equation.
- 3)  $\partial_\mu \partial^\mu R - R (\partial^\mu \theta - A^\mu) (\partial_\mu \theta - A_\mu) + dV/dR = 0$  Radial/amplitude equation.

Neutrality Condition

Charge density:

$$\rho \equiv J_{em}^0 = 2R^2 (A_0 - \partial_0 \theta)$$

Neutrality requires:  $\rho = 0$

$$\Rightarrow \boxed{\begin{aligned}A_0 &= \partial_0 \theta = q\omega \\ \rho &= 0 \text{ when } q\omega = A_0\end{aligned}}$$

**Neutral fermions** in our model satisfy  $\partial^\mu \theta - A^\mu = 0$  (locally “comoving” with the EM potential), while **charged** fermions have a nonzero mismatch that sources EM fields.

In the **Standard Model (SM)**

Charge is not defined by a relation like  $q\omega = A_0$ .

Instead, it comes from the **electroweak gauge symmetry**:

$$Q = T_3 + \frac{Y}{2},$$

- $T_3$  : the 3rd component of weak isospin (from  $SU(2)_L$ )
- $Y$  : weak hypercharge (from  $U(1)_Y$ ).

This relation is **exact** after electroweak symmetry breaking, when the photon emerges as the unbroken gauge field.

When does  $Q = 0$  (vanishing charge)?

It happens whenever the quantum numbers satisfy:

$$T_3 = -\frac{Y}{2}.$$

Examples:

- **Neutrinos:**

$$T_3 = +\frac{1}{2}, Y = -1 \Rightarrow Q = 0.$$

- **Neutron (udd):**

Quark charges:

- o u:  $+2/3$ ,
- o d:  $-1/3$ .

$$\text{sum} = +2/3 - 1/3 - 1/3 = 0.$$

- **Gauge bosons:**

- o Photon ( $\gamma$ ) and Z boson:  $Q = 0$ .
- o W bosons:  $Q = \pm 1$ .

The key difference between our model to the SM

**In SM:** Neutrality is purely an algebraic result of isospin–hypercharge assignments.

**In Our model:** Neutrality is a *dynamical balance* condition ( $q\omega = A_0$ ) between internal oscillation and external potential.

## 22. Fractional Quark Charges in the Coupled-Fields Model Electromagnetic Current from Coupled Fields

Each fermion consists of two real two-component fields (“strings”):

$$\Phi_a(x) = \begin{pmatrix} \varphi_{a1} \\ \varphi_{a2} \end{pmatrix} \text{ with } a = 1, 2 \tag{49}$$

Using the antisymmetric generator

$$\varepsilon = \begin{bmatrix} 0 & 1 \\ -1 & 0 \end{bmatrix} \tag{50}$$

the electromagnetic current is defined as

$$j_{em}^\mu = \kappa \sum_a (-1)^{a-1} \Phi_a^T \varepsilon \overline{D}_\mu \Phi \tag{51}$$

This identifies electromagnetism with the relative rotation between the two strings.

### Relative Phase Variable

Introduce amplitude–phase variables:

$$\Phi_a = \rho_a \begin{pmatrix} \cos \theta_a \\ \sin \theta_a \end{pmatrix} \tag{52}$$

Define center and relative phases

$$\theta_c = (\theta_1 + \theta_2)/2, \quad \Delta\psi = \theta_1 - \theta_2. \quad (53)$$

Then the current reduces to:

$$j_{em}^\mu \propto (\partial^\mu \Delta\psi + gA^\mu) \quad (54)$$

so, the electric charge is the Noether charge of the relative phase  $\psi$ .

### 23. Three-Fold Locking from Color

Color interactions generate a locking potential:

$$V_{lock}(\Delta\psi) = \Lambda^4 [1 - \cos(3\Delta\psi)] \quad (55)$$

with minima at  $\psi = 0, 2\pi/3, 4\pi/3$ .

This structure mirrors color triplicity and stabilizes fractional offsets.

#### Origin of the Locking Stiffness.

The stiffness of the three-fold locking potential is set dynamically by the confining dynamics of QCD. At energies below the confinement scale

$\Lambda_{QCD} \sim 200 - 300 \text{ MeV}$ , color interactions induce an effective periodic potential in the relative phase  $\psi$  through virtual gluon exchange and quark condensate formation. The amplitude of this potential is determined by the vacuum expectation value of color-charged condensates and the nonperturbative gluonic field energy that resists phase delocalization. Consequently, the curvature of the minima—*i.e.*, the stiffness—is controlled by the confinement strength: a stronger confining vacuum generates a deeper, sharper locking potential and stabilizes fractional offsets. Because this mechanism is tied to the universal QCD scale, the fractional charges are naturally robust and do not require fine-tuning. At high energies ( $E \gg \Lambda_{QCD}$ ), asymptotic freedom weakens the locking, while at low energies the confined phase enforces phase locking, making the stiffness a direct manifestation of the nonperturbative QCD vacuum structure.

The stiffness of the locking potential is set by nonperturbative QCD confinement: gluon-mediated interactions and quark condensates generate an effective three-fold periodic potential whose curvature is controlled by the confinement scale  $\Lambda_{QCD}$ , stabilizing fractional phase offsets.

### 24. Charge Quantization Rule

The integrated charge is proportional to the phase shift:

$$Q/e = \Delta\psi/\pi. \quad (56)$$

Calibrating so that  $\Delta\psi = \pi$  corresponds to  $|Q| = 1$  (electron), we obtain fractional charges when

$$\Delta\psi = \pm\pi/3 \text{ or } \Delta\psi = \pm 2\pi/3. \quad (57)$$

### 25. Leptons and Quarks

Neutrino:  $\Delta\psi = 0 \Rightarrow Q = 0$

Electron:  $\Delta\psi = \pm\pi \Rightarrow Q = \mp 1$

Up quark:  $\Delta\psi = +\frac{2\pi}{3} \Rightarrow Q = +\frac{2}{3}$

Down quark:  $\Delta\psi = -\frac{\pi}{3} \Rightarrow Q = -\frac{1}{3}$

*Color* corresponds to the three degenerate minima  $\psi_k$  but the same electric charge.

## 26. Hadron Charge Consistency

Proton (uud):  $2\left(\frac{2\pi}{3}\right) + \left(-\frac{\pi}{3}\right) = \pi \Rightarrow Q = +1$

Neutron (udd):  $\left(\frac{2\pi}{3}\right) + 2\left(-\frac{\pi}{3}\right) = 0 \Rightarrow Q = 0$

$\pi^+$  (uanti-d):  $\left(\frac{2\pi}{3}\right) - \left(-\frac{\pi}{3}\right) = \pi \Rightarrow Q = +1$

Thus, hadron charges emerge correctly as integers.

### A) Nature of the Binding Exchange Boson

The coupled-string fermion must be bound by an internal mediator. Two consistent realizations are possible:

- a) a massive vector
- b) a massive scalar.
- 1) A Vector Mediator

For a heavy mediator  $m_B$ , introduce a Proca field  $B_\mu$  coupled to the SO(2) current  $J = A^2 \partial_\mu \theta$ :

$$\mathcal{L}_B = -\frac{1}{4} G_{\mu\nu} G_{\mu\nu} + \frac{1}{2} m_B^2 B_\mu B_\mu + g B_\mu J_\mu$$

Integrating out  $B_\mu$  at tree level yields:

$$\Delta\mathcal{L}_{eff} = \left(\frac{g^2}{2m_B^2}\right) J_\mu J_\mu = \left(\frac{g^2}{2m_B^2}\right) A^4 \left[\dot{\theta}^2 - (\nabla\theta)^2\right] \tag{58}$$

This renormalizes the effective inertia  $I \rightarrow I_{eff}$ . The spectrum of rotor levels becomes:

$$E_n = (n\hbar - \kappa I_{eff})^2 / (2I_{eff}) + const. \tag{59}$$

Thus, the mediator mass  $m_B$  controls the level spacing of internal excitations.

### 2) A Scalar Mediator

Keep SO(2) exact by letting the binding act only on the invariant  $A^2 = \phi_1^2 + \phi_2^2$ .

Introduce a scalar  $\sigma$  coupled to  $A^2 = \phi_1^2 + \phi_2^2$ :

$$\mathcal{L}_\sigma = \frac{1}{2} (\partial\sigma)^2 - \frac{1}{2} m_\sigma^2 \sigma^2 - g_\sigma \sigma A^2 \tag{60}$$

with  $(\partial\sigma)^2 \equiv \partial_\mu \partial_\mu$

Integrating out  $\sigma$  gives:

$$\sigma \approx m_\sigma^2 g_\sigma A^2 \Rightarrow \Delta\mathcal{L}_{eff} = -\left(g_\sigma^2 / 2m_\sigma^2\right) A^4 \tag{61}$$

This stiffens the radial potential and the amplitude fluctuation  
 $A(x) = A_0 + \rho(x)$  with mass:

$$m_\rho^2 = \frac{\partial^2}{\partial A^2} \left[ V(A^2) - (g_\sigma^2/2m_\sigma^2) A^4 \right] \text{ at } A = A_0 \quad (62)$$

The range of the binding force is then  $R \approx \hbar/(m_\rho c)$ , yielding Yukawa-type behavior.

B) Consistency with  $\kappa = \hbar/e$

From the rotor quantization,  $Q = n\hbar$ . With minimal coupling,  $Q_{phys} = ne$ . This matches the heuristic relation  $Q = (\hbar/\kappa)n$  provided  $\kappa = \hbar/e$ .

Thus, the previously introduced  $\kappa$ -term is consistent with charge quantization when tied to the electron charge.

## 27. Experimental Outlook

The coupled-fields model is directly falsifiable. If future collider measurements continue to show no deviation in Bhabha scattering [5]-[9] up to compositeness scales  $\Lambda > 50 - 100$  TeV, or if precision constraints on the electron anomalous magnetic moment improve by two orders of magnitude without revealing the predicted shift, then the internal rotor interpretation would be experimentally ruled out. Similarly, any demonstration of the electron's point-like nature at length scales below  $10^{-21}$  m would contradict the predicted effective charge radius.

1) Vector mediator: Internal excitation level spacings depend on  $I_{eff}$ , and thus on  $m_B$ . High-intensity field experiments probing  $n \rightarrow n \pm 1$  transitions could constrain  $m_B/g$ .

2) Scalar mediator: The radial mode  $\rho$  has finite range  $R = \hbar/(m_\rho c)$ . High-energy scattering or electron polarizability measurements could test deviations consistent with finite-range binding.

## 28. Experimental Implications

List of benchmark predictions

### Effective Electron Radius

The effective radius is estimated as:

$$\text{For } \Lambda = 10 \text{ TeV: } r_e^{eff} = 1.973 \times 10^{-20} \text{ m}$$

### Bhabha Scattering Deviation

$$\delta\sigma/\sigma \approx s/\Lambda^2$$

### Anomalous Magnetic Moment Shift

Estimated as:

$$\delta a_e \approx c_e (m_e^2/\Lambda^2), \text{ with } c_e \sim O(0.1-1)$$

For  $\Lambda = 10$  TeV:

$$\delta a_e \approx (2.6 \times 10^{-15}) \times c_e \quad (63)$$

Current experimental uncertainty in  $a_e$  is  $\sim 10^{-13}$ , so this effect lies below current reach but could be probed in the future.

The radius of matter particles plays an important role in nuclear physics and astrophysics. According to Kaluza-Klein theory [10]-[13], the exact radii of electron and proton are obtained.

According to PDG (Particle Data Group) [14], the classical electron radius, also known as the Thomson scattering length, is approximately  $2.8179 \times 10^{-15}$  meters. This is a theoretical value derived from classical physics and does not represent the actual physical size of the electron, which is considered a point particle. The estimates may be tested by different ways:

- Charge distribution inside the electron may be detectable via high-energy scattering.
- Variation of charge under external field disruption (e.g., strong laser fields).
- Charge neutrality of decomposed components could be tested in low-temperature field separation setups.

Below I summarize the predictions and give the key formulas to clarify exactly what's being tested. I use derivations from above (compact phase, minimal coupling, mediator integration).

**Effective electron “charge radius”  $r_e$**

**Model:** The electron’s charge is spread by the internal rotor; integrating out the binding mediator at a scale  $\Lambda \equiv m_B/g$  generates a finite-size form factor

$$F_1(Q^2) \cong 1 - \frac{1}{6} Q^2 r_e^2 \quad \text{with} \quad r_e \approx \frac{\hbar c}{\Lambda}. \tag{64}$$

**SM:**  $r_e = 0$  at tree level point-like (the **lowest-order approximation** to a physical process—the contribution that comes directly from the **basic Feynman diagrams with no closed loops**, with only tiny loop-structure effects.)

### 29. Numerical Predictions Distinguishing the Coupled-Field Model from the Standard Model

Benchmarks for the compositeness scale  $\Lambda$ . Quantities shown:

- Effective electron charge radius:  $r_e = \hbar c/\Lambda$
- Electron anomalous magnetic moment shift:  $\delta a_e \approx \kappa_g (m_e/\Lambda)^2$  with  $\kappa_g \in [0.1, 1]$
- Bhabha scattering fractional deviation:  $\delta\sigma/\sigma \approx Q^2/(6Q\Lambda^2)$  at chosen  $Q$
- Positronium 1S–2S frequency shift from finite lepton size:  

$$\delta\nu \approx (7/8) * (2/3) * \alpha^4 m_r^3 (1/\Lambda^2) (e/h)$$

**Table 4.** Numerical predictions of the CF model.

$\Lambda$ (TeV)	$r_e$ (m)	$\delta a_e$ (min)	$\delta a_e$ (max)	$\delta\sigma/\sigma$ @ 200 GeV	$\delta\sigma/\sigma$ @ 1 TeV	$\delta\nu_{ps}$ (1S-2S) (Hz)
10	$1.973e^{-20}$	$2.611e^{-16}$	$2.611e^{-15}$	$6.667e^{-05}$	$1.667e^{-03}$	$6.671e^{-05}$
20	$9.866e^{-21}$	$6.528e^{-17}$	$6.528e^{-16}$	$1.667e^{-05}$	$4.167e^{-04}$	$1.668e^{-05}$
50	$3.947e^{-21}$	$1.044e^{-17}$	$1.044e^{-16}$	$2.667e^{-06}$	$6.667e^{-05}$	$2.668e^{-06}$
100	$1.973e^{-21}$	$2.611e^{-18}$	$2.611e^{-17}$	$6.667e^{-07}$	$1.667e^{-05}$	$6.671e^{-07}$

**Table 4:** Numerical predictions of the coupled-fields model at benchmark compositeness scales  $\Lambda$ . Listed are the effective electron charge radius, the induced shift in the anomalous magnetic moment, and the fractional deviation in Bhabha scattering at  $\sqrt{s} = 200 \text{ GeV}$  and  $\sqrt{s} = 1 \text{ TeV}$ . For comparison, the Standard Model predicts a point-like electron at tree level and no such deviations beyond radiative corrections. For instance, at  $\Lambda = 10 \text{ TeV}$  we predict:  $r_e \approx 2 \times 10^{-20} \text{ m}$ ,  $\delta\sigma/\sigma \approx 0.17\%$ ,  $\delta a_e \approx 10^{-15}$ .

(These come directly from the above mediator picture and the compact-phase formalism.)

**Observable:** Small, energy-dependent deviations in **Bhabha scattering** and other high- $Q^2$  processes:

$$1) \frac{\delta\sigma}{\sigma} \sim \frac{Q^2 r_e^2}{6} \approx \frac{Q^2}{6\Lambda^2}.$$

Examples (from the attached **Table 4**):

- At  $Q = 200$ :  $\delta\sigma/\sigma \approx 6.7 \times 10^{-5}$  for  $\Lambda = 10 \text{ TeV}$ ; scales down as  $1/\Lambda^2$ .
- At  $Q = 1 \text{ TeV}$ :  $\delta\sigma/\sigma \approx 1.7 \times 10^{-3}$  for  $\Lambda = 10 \text{ TeV}$ .

### 30. Anomalous Magnetic Moment Shift $\delta a_e$

**Model:** Composite/rotor dynamics induce a Pauli-type operator at the scale  $\Lambda$ , giving

$$2) \delta a_e \sim \kappa_g (m_e/\Lambda)^2 \text{ with } \kappa_g \in [0,1,1]$$

where  $\kappa_g$  encodes UV details of the binding (vector vs. scalar route as outlined above).

**SM:** Predicts  $a_e$  from QED/EW loops without this  $1/\Lambda^2$  term.

As can be seen in **Table 4**, there is a dedicated fit that combines  $a_e$  with an independent  $\alpha$  could bound (or detect)  $\Lambda$  within my framework.

### 31. Numerical Predictions from the Coupled-Strings

Here we present definite numerical predictions from the coupled-strings model that differ from the Standard Model and can be tested at near-future precision experiments. We focus on three quantities: the effective electron radius, Bhabha scattering deviations, and the anomalous magnetic moment shift.

Effective Electron Radius

The effective radius is estimated as:

$$3) r_e^{\text{eff}} = \frac{\hbar c}{\Lambda}$$

For  $\Lambda = 10 \text{ TeV}$ :

$$r_e^{\text{eff}} = 1.973 \times 10^{-20} \text{ m}$$

Rule of thumb:  $r_e^{\text{eff}} \propto 1/\Lambda$  (LEP/ILC contact-interaction literature uses this mapping widely; see reviews on Bhabha contact operators).

### 32. Bhabha Scattering Deviation

Fractional deviation is approximated as:

$$4) \frac{\delta\sigma}{\sigma} \approx \frac{s}{6\Lambda^2}$$

Numerical values:

- At  $\sqrt{s} = 1 \text{ TeV}$ ,  $\Lambda = 10 \text{ TeV}$ :  $\delta\sigma/\sigma \approx 1.7 \times 10^{-3}$  (0.17%)
- At  $\sqrt{s} = 240 \text{ GeV}$ ,  $\Lambda = 10 \text{ TeV}$ :  $\delta\sigma/\sigma \approx 9.6 \times 10^{-5}$

### 33. Anomalous Magnetic Moment Shift

Estimated as:

$$\delta a_e \approx c_e \left( m_e^2 / \Lambda^2 \right), \text{ with } c_e \sim O(0.1-1)$$

For  $\Lambda = 10 \text{ TeV}$ :

$$5) \delta a_e \approx (2.6 \times 10^{-15}) \times c_e$$

Current experimental uncertainty in  $a_e$  is  $\sim 10^{-13}$ , so this effect lies below current reach but could be probed in the future

### 34. Conclusion

At a benchmark  $\Lambda = 10 \text{ TeV}$ , the model predicts:

- Effective electron radius  $r_e^{\text{eff}} = 1.97 \times 10^{-20} \text{ m}$
- Bhabha scattering deviation  $\delta\sigma/\sigma = 0.17\%$  at  $\sqrt{s} = 1 \text{ TeV}$ , or  $9.6 \times 10^{-5}$  at  $\sqrt{s} = 240 \text{ GeV}$
- Anomalous magnetic moment shift  $\delta a_e \sim 10^{-15}$

These predictions contrast with the Standard Model, where the electron is point-like at tree level, and provide concrete experimental tests for the coupled-strings model.

These predictions *quantitatively* operationalize the qualitative story developed in this manuscript (compact-phase quantization, minimal coupling, mediator integration).

### 35. Comparing the Real Coupled Fields Model with Kaluza-Klein and Preons

1) Kaluza-Klein (KK) idea [10]-[13]:

- Electric charge emerges as momentum in an *extra compact spatial dimension*.
- Gauge fields (like electromagnetism) are components of a higher-dimensional metric.
- Quantization of charge comes from discrete momentum modes along the compactified dimension.

**Coupled fields model [1]-[4]:**

- Works **strictly in ordinary 3 + 1 spacetime**, no need for extra dimensions.
- Charge is not momentum in an unseen dimension but **an emergent conserved current** from the **rotation of two coupled real fields** in internal field space.

- Quantization is topological (winding numbers, rotational symmetry breaking) rather than geometric compactification.

**Key distinction:**

In KK, charge is *geometric in higher dimensions*. In this model, charge is *dynamical and topological in coupled real fields within  $3 + 1D$  spacetime*.

**Preon/compositeness idea [15]-[19]:**

- Electrons and quarks are not fundamental, but composed of smaller, point like constituents (preons).
- Charge is assigned to preons, and the observed electron charge is the sum of its constituents' charges.
- Faces difficulties: confinement mechanism, anomaly cancellation, huge energy scales.

**Coupled fields model [1]-[4]:**

- Does **not posit smaller constituent particles**. Instead, the electron is a **bound state of two coupled real fields**—continuous structures, not discrete preons.
- Charge is **not assigned arbitrarily to subcomponents**. It **emerges naturally** from the rotational coupling and Noether current, meaning it is a *derived property*, not a fundamental input.
- Avoids preon problems (arbitrary charge assignments, huge unexplained binding energies, lack of experimental evidence).

In preon models, charge is **postulated and compositional**. In this model, charge is **emergent and dynamical** from field coupling.

## 36. Philosophical/Conceptual Difference

- **Kaluza-Klein**: Reduces charge to geometry (but requires extra unobserved dimensions).
- **Preons**: Reduces charge to constituent bookkeeping (but faces difficulties explaining).
- **Coupled fields**: Reduces charge to a **conserved rotational current** of coupled fields, directly tied to Planck's constant.

An important advantage of the coupled-fields construction is that the continuous  $SO(2)$  current does not introduce fermionic gauge anomalies requiring delicate cancellation conditions. Since charge emerges from a single continuous symmetry, anomaly consistency follows automatically, avoiding the intricate charge bookkeeping required in preon models.

This makes the coupled fields approach closer in spirit to how **spin** is emergent from rotation in quantum fields, rather than a hidden label.

**Summary:**

The coupled field model is distinct because it keeps everything in **4D spacetime**, avoids unobserved **extra dimensions** or **hypothetical constituents**, and provides a **dynamical, topological mechanism** for charge that directly links it with  **$\hbar$  and coupling constants**.

## 37. Conclusions

In this work we have reinterpreted electric charge as an emergent property of coupled real fields rather than as a fundamental, intrinsic label of matter. By representing fermions as bound configurations of two interacting string-like fields in ordinary spacetime, we showed that charge arises as a conserved Noether current generated by internal rotation. Quantization follows naturally from the compactness of the internal phase, linking the discrete values of charge directly to Planck's constant and the coupling parameter  $\kappa = \hbar/e$ .

By avoiding unobserved extra dimensions and arbitrary constituent preons, the coupled-strings model provides a mathematically grounded explanation for charge as an emergent dynamical property within  $3 + 1$  spacetime, directly linked to Planck's constant.

Importantly, in the limit  $\Lambda \rightarrow \infty$ , the emergent charge radius  $r_e \rightarrow 0$ , all higher-order rotor excitations decouple, and the electron becomes point-like. In this limit, the coupled-fields model continuously reduces to the Standard Model prediction. This ensures phenomenological compatibility with all presently observed bounds, while offering a controlled pathway to detect deviations at future facilities.

This reinterpretation provides not only a conceptual foundation for electric charge but also a roadmap for experimental tests at future colliders.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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