Emergent Electrodynamics and Charge Quantisation on the Error-Correcting Vacuum

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Abstract

Following the derivation of the Strong Gravity scale from the $[8, 4, 4]$ error-correcting tensor network, we extend the discrete lattice framework to recover the core phenomenology of Quantum Electrodynamics. Rather than inserting continuous gauge groups and arbitrary parameters by hand, we demonstrate that electrodynamics emerges as the geometric shadow of the underlying quantum error-correcting vacuum. By projecting the antisymmetric vacuum flux into the 3D T_{1u} vector representation of the Octahedral (O_h) group, we prove that the photon is topologically protected from acquiring a mass gap, in stark contrast to the massive spin-2 graviton. We demonstrate that physical fractional electric charges ($+2/3$, $-1/3$) natively emerge when the $U(1)$ topological operator evaluates the broken symmetry of confined $SU(3)$ colour defects. Furthermore, we evaluate the Pauli Z-stabilisers of the $[8, 4, 4]$ code, identifying a structural correspondence to continuous $U(1)$ gauge invariance that recontextualises charge conservation as the vacuum actively suppressing phase errors. By evaluating the geometric flux through lattice plaquettes, we verify the framework's consistency with standard lattice gauge theory, confirming that the discrete topology natively preserves the Bianchi identity and Faraday's Law. Finally, we show that the bare inverse fine-structure constant ($1/\alpha_0 = 137$) derives from the $T(16)$ topological capacity of the bipartite scattering space.

Audit note (added 2026-05-31). This paper predates the framework's methodology audit of 2026-05-30. The structural results (massless-photon topological protection via T_{1u}; $U(1)$ stabilizer correspondence; Bianchi identity and Faraday's law as plaquette structures; fractional charges $\pm 2/3, \pm 1/3$ from $SU(3)$ defect species) are at Locked / class-3 tier per ANCHOR §15 item 116 and survive the audit unchanged. **§16.3 caveat on** $1/\alpha_0 = 137$: the derivation as $T(16) + 1 = 137$ (16th triangular number + 1, from "bipartite scattering capacity") is a single-step integer identification with bounded but non-zero competing routes (the duplicate `TCH_Coulomb_law` paper presents the same headline via a different framing — this duplication is itself an audit datum). The headline should be read post-audit as "bare $\alpha_0^{-1} = 137$ is one structural route consistent with the substrate; the dressed value 137.036 remains an open gap", i.e. Proposition tier pending search-space audit. **Item 79 dependency**: the bipartite tensor structure underlying photon mass protection and fractional-charge derivation rests on the Bipartite Grassmann Trace Theorem (currently a promotion target).

1 Introduction: The Geometric Origin of the Gauge Sector

In the continuum Standard Model, the electromagnetic force is introduced axiomatically via the $U(1)$ gauge group. The coupling constant (α), the masslessness of the photon, and the specific fractional quantisation of quark charges are treated as fundamental empirical inputs.

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In this paper, we propose that electrodynamics is not a fundamental axiomatic force, but rather a necessary thermodynamic and geometric consequence of a discrete, $[8, 4, 4]$ quantum error-correcting tensor network. Building upon previous work that derived the Strong Gravity scale from the symmetric strain of this lattice [4], we now evaluate the antisymmetric flux and local phase geometries of the same network. We demonstrate that the core structural features of QED can be derived from the boundary conditions and logical stabilisers of the lattice graph.

2 Topological Protection of the Massless Photon

To model the electromagnetic vector field, we must isolate the spin-1 photon from the turbulent quantum vacuum. In the Octahedral (O_h) group governing the discrete 3D lattice, a vector field transforms under the 3-dimensional T_{1u} representation.

Unlike the spin-2 graviton, which is isolated via symmetric mechanical strain, the photon is generated by the antisymmetric directed flux of the vacuum Hamiltonian:

$$\partial H_{\text{anti}} = H_{\text{forward}} - H_{\text{backward}} \tag{1}$$

We evaluate the quantum vacuum by filtering this antisymmetric matrix through the exact T_{1u} Clebsch–Gordan projector, constructed from the character-weighted sum over all 48 elements of O_h:

$$P_{T_{1u}} = \frac{3}{48} \sum_{g \in O_h} \chi_{T_{1u}}(g)^* \, R_g \tag{2}$$

The resulting energy spectrum reveals a strict topological protection mechanism, rooted in a fundamental distinction between the photon and graviton representations:

Theorem 1 (Photon Mass Protection)**.** *Any real antisymmetric matrix projected into an odd-dimensional irreducible representation of O_h must possess at least one exactly zero eigenvalue. The T_{1u} photon representation is 3-dimensional (odd); therefore the photon is topologically forbidden from acquiring a mass gap. The E_g graviton representation is 2-dimensional (even); therefore the graviton is permitted to have a non-zero mass gap.*

Proof. The eigenvalues of a real antisymmetric matrix come in conjugate pairs $\pm i\lambda$. In a d-dimensional space, these pairs account for at most $2\lfloor d/2 \rfloor$ eigenvalues. When d is odd, at least one eigenvalue must be exactly zero. For T_{1u} ($d = 3$): one pair $\pm i\lambda$ plus one mandatory zero. For E_g ($d = 2$): one pair $\pm i\lambda$ with no mandatory zero. □

Our computational evaluation confirms this: the T_{1u} mass gap is exactly 0.000 GeV, while the E_g graviton acquires a non-zero stiffness of ~ 0.22 GeV. The latter is the band curvature evaluated at the stable minimum $k = \pi/2$ of the period-4 rolled vacuum reached after the spontaneous symmetry breaking of the Γ-point E_g tachyon (see [4] for the underlying tachyonic-rolling dynamics on the $\mathbb{Z}^3 \otimes Q_3$ substrate). The discrete lattice architecture simultaneously derives an $\mathcal{O}(1)$ GeV bare strong-gravity Planck scale (via the E_g stiffness) while mathematically forbidding the vector photon from acquiring mass (via the T_{1u} zero).

3 Emergent Fractional Charge Quantisation

In the Standard Model, the fractional electric charges of quarks ($+2/3$, $-1/3$) and the integer charges of leptons (-1, 0) are assigned phenomenologically. On the $[8, 4, 4]$ lattice, electric charge (Q) is not an intrinsic property, but rather an emergent topological eigenvalue.

We map the Gell-Mann–Nishijima formula to the discrete lattice using the underlying Pauli Z-phase operators. The electric charge evaluates the flavour-isospin sign Z_f, the sum of the three colour-sector operators $\sum_i Z_{c_i}$, and a global matter/antimatter parity eigenvalue Z_p:

$$Q = \frac{1}{2}\, Z_f + \frac{1}{3}\sum_i Z_{c_i} + \frac{1}{2}\, Z_p \tag{3}$$

- $Z_f = \mathrm{sgn}(I_3)$ is the flavour-isospin sign, i.e. the I_3 bit of the $[8,4,4]$ register read in ± 1 eigenvalue form. It is *not* an additional register bit.
- The three colour-sector operators Z_{c_i} ($i \in \{r, g, b\}$) are one-hot stabilisers built from the two physical colour qubits (C_0, C_1) of the $[8,4,4]$ register. Each Z_{c_i} takes eigenvalue $+1$ on the unique two-qubit configuration assigned to colour i and -1 on the other three configurations:

$$\begin{aligned} Z_{c_r} &= +1 \text{ on } |C_0C_1\rangle = |01\rangle, \quad -1 \text{ otherwise} \\ Z_{c_g} &= +1 \text{ on } |C_0C_1\rangle = |10\rangle, \quad -1 \text{ otherwise} \\ Z_{c_b} &= +1 \text{ on } |C_0C_1\rangle = |11\rangle, \quad -1 \text{ otherwise} \end{aligned}$$

  The combinatorial origin of the four eigenvalue patterns (one singlet $|00\rangle$ + three triplet vertices) is the R3 constraint of the $[8,4,4]$ construction together with the $\mathbb{F}_2$ XOR closure of the three-colour algebra $R \oplus G \oplus B = (0,0)$ on the colour subspace; the one-hot $\{Z_{c_i}\}$ basis is the operator dual of this XOR-closed codeword basis.

- $Z_p = \pm 1$ is a *global* $\mathbb{Z}_2$ tag on the matter/antimatter doublet, *not* a 9th register bit. Antimatter is implemented as the CPT bitwise inversion $\bar{\mathbf{c}} = \mathbf{1} \oplus \mathbf{c}$ of the entire 8-bit codeword (preserving the frustration count $F(\bar{\mathbf{c}}) = F(\mathbf{c})$ and hence the bare mass); Z_p is the eigenvalue under this global involution, $Z_p = +1$ on the matter copy and -1 on the antimatter copy.

Lepton codewords (with $|C_0C_1\rangle = |00\rangle$ as enforced by R3 of the $[8,4,4]$ construction) sit at the singlet point where all three $Z_{c_i} = -1$, giving $\sum_i Z_{c_i} = -3$. Quark codewords (with $|C_0C_1\rangle \neq |00\rangle$ by R3) sit on a colour-triplet vertex where exactly one $Z_{c_i} = +1$ and the other two equal -1, giving $\sum_i Z_{c_i} = -1$. With $Z_p = +1$ on matter codewords (and $Z_p = -1$ on antimatter, ensuring CPT symmetry of charge assignments), the formula then yields:

particle	Z_f	$\sum_i Z_{c_i}$	Z_p	predicted Q	SM value
neutrino (ν)	$+1$	-3	$+1$	$+\frac{1}{2} - 1 + \frac{1}{2} = 0$	0
charged lepton (e^-)	-1	-3	$+1$	$-\frac{1}{2} - 1 + \frac{1}{2} = -1$	-1
up-type quark (u)	$+1$	-1	$+1$	$+\frac{1}{2} - \frac{1}{3} + \frac{1}{2} = +\frac{2}{3}$	$+\frac{2}{3}$
down-type quark (d)	-1	-1	$+1$	$-\frac{1}{2} - \frac{1}{3} + \frac{1}{2} = -\frac{1}{3}$	$-\frac{1}{3}$

The four eigenvalue patterns exhaust the matter sector; the twelve Standard Model fermion species (three generations $\times$ four matter classes: neutrino, charged lepton, up-type quark, down-type quark) reproduce these charges exactly when their codewords are evaluated against Eq. (3) with the one-hot decomposition above. The match is parameter-free: the weights $\{1/2, 1/3, 1/2\}$ are fixed by the Gell-Mann–Nishijima structure, and the eigenvalue patterns are forced by R3 of the $[8,4,4]$ construction.

Evaluating the raw combinatorial space without the confinement constraint yields non-standard charges (e.g., $Q = +2$). However, these states possess severe colour-trace misalignment, representing highly excited, unconfined topological defects. The lattice string tension natively projects these unphysical charges out of the stable low-energy spectrum, ensuring that only the canonical fractional charges manifest as observable asymptotic states.

This result demonstrates that fractional electric charge is the $U(1)$ geometric shadow cast by $SU(3)$ colour confinement: the charge quantisation and the confinement constraint are not independent features of the Standard Model, but two aspects of a single topological structure on the $[8,4,4]$ code.

4 Gauge Invariance as Quantum Error Correction

Electrodynamics fundamentally relies on local $U(1)$ gauge invariance—the physical requirement that the universe remains symmetric under local phase transformations ($|\psi\rangle \to e^{i\theta}|\psi\rangle$).

In our framework, this continuous symmetry is modelled as the macroscopic limit of discrete quantum error correction. A local phase transformation corresponds to the application of Z-operators across specific lattice nodes. In the stabiliser formalism, the physical vacuum (the logical subspace) is defined as the $+1$ eigenspace of the code's stabiliser generators.

By evaluating the four Z-stabiliser generators of the $[8,4,4]$ code against the valid fermion states, our simulation confirmed that every physical state returns an exact $+1$ eigenvalue for all four stabilisers. While these four discrete, global topological stabilisers do not formally equate to an infinite-dimensional, continuous local $U(1)$ gauge symmetry, they provide a highly suggestive structural correspondence. What continuum physics models as smooth, continuous conservation of charge may originate discretely as the underlying tensor network utilising phase stabilisers to project local phase errors out of the logical subspace.

Conjecture 1 (Gauge–QEC Correspondence)**.** *In the continuum limit, the Z-stabiliser structure of the $[8,4,4]$ code reproduces the full local $U(1)$ gauge invariance of QED. The four discrete stabiliser generators correspond to the four independent $U(1)$ phase constraints at each lattice vertex, and the projection onto the $+1$ eigenspace is the discrete precursor of Gauss's law ($\nabla \cdot E = \rho$).*

The exact mapping between these discrete stabiliser limits and arbitrary local phase rotations remains an open problem for future continuum-limit studies. Structurally, this is the Z-side half of a broader Z/X-stabilizer unification programme on the $\mathbb{Z}^3 \otimes Q_3$ substrate: the Z-stabilizers $\{Z_i Z_j\}_{(i,j)\in Q_3}$ on the matter cell's internal qubits generate the mass mechanism via syndrome-weight elastic strain [5], while the X-type stabilizer operations on the truncated-cube gauge bridges generate the Wilson-loop holonomies of the gauge sector [4]. Under the strict self-duality of the $[8,4,4]$ extended Hamming code, a CSS-style combination of the two would unify the matter-cell mass code and the gauge-cell electrodynamics code into a single quantum-error-correcting structure.

5 Consistency with Lattice Gauge Theory: Maxwell's Equations

To demonstrate that the dynamical behaviour of the electromagnetic field is compatible with our discrete geometry, we employ Wilson's formulation of lattice gauge theory [1]. In this framework, the continuous field strength tensor ($F_{\mu\nu}$) is represented by the discrete flux through a plaquette—a closed 4-node cycle on the tensor network.

It is a known topological identity of cubic lattices that the boundary of a closed 3D volume has no further 2D boundary ($\partial\partial V = 0$). By isolating a 3D sub-cube within our specific $[8,4,4]$ network and assigning chaotic $U(1)$ gauge vector potentials (A_μ) to its directed links, our simulations confirmed exact geometric annihilation of the net outward flux:

$$\sum_{\text{faces}} F_{\mu\nu} = 0 \qquad \text{(to machine precision)} \tag{4}$$

This demonstrates that the $[8,4,4]$ error-correcting vacuum natively preserves the Bianchi identity ($\nabla \cdot B = 0$) and Faraday's Law. While this topological identity is a general feature of lattice models [1], its seamless integration acts as a crucial consistency check, confirming that the error-correcting graph is a mathematically valid geometric host for classical electrodynamics.

6 The Bare Fine-Structure Constant

In our framework, the bare inverse fine-structure constant is derived as the topological capacity of the discrete interaction space. During the fundamental scattering of two disjoint 8-face oblate square bipyramid cells (Q_3 cells), the total phase space is governed by $8+8=16$ face elements. The number of internal bipartite configurations respecting the exchange symmetry between the two voids is precisely the 16th triangular number:

$$T(16) = \frac{16 \times 17}{2} = 136 \tag{5}$$

Adding the single external forward-scattering channel yields the bare coupling:

$$\frac{1}{\alpha_0} = T(16) + 1 = 137 \tag{6}$$

This integer result, derived entirely from the face count of two oblate bipyramid cells, agrees with the measured $\alpha^{-1} = 137.035999\ldots$ to 0.026%.

We note an intriguing combinatorial observation regarding higher-order corrections. The shortest closed quantum walk (vacuum polarisation loop) across the 8-bit geometry has an amplitude of $1/\binom{8}{2} = 1/28$. Suppressing this loop against the 128-state fermion background yields a second-order amplitude of $1/(28 \times 128) = 1/3584$. Summing these with the bare value gives:

$$\frac{1}{\alpha_{\text{eff}}} \approx 137 + \frac{1}{28} + \frac{1}{3584} \approx 137.0360 \tag{7}$$

which is remarkably close to the empirical CODATA value. However, reconciling these static discrete combinatorial paths with the logarithmic energy dependence of standard QED vacuum polarisation ($\Delta\alpha^{-1} \propto \frac{2\alpha}{3\pi}\ln(\Lambda/m_e)$) remains an outstanding challenge. We present the tree-level integer 137 as a rigid geometric artefact of the lattice scattering space, while the physical validity of the discrete loop corrections is left as a subject for future investigation.

7 Conclusion

We have demonstrated that treating the quantum vacuum as a discrete, error-correcting $[8, 4, 4]$ tensor network naturally resolves many of the foundational structures of Quantum Electrodynamics. The principal results are:

1. **Photon mass protection** (proven): The masslessness of the photon is a topological consequence of the odd-dimensionality of the T_{1u} representation under O_h. Any real antisymmetric matrix projected into an odd-dimensional space must have a zero eigenvalue. The spin-2 graviton (E_g, 2D, even) is permitted a mass gap; the spin-1 photon (T_{1u}, 3D, odd) is forbidden one.

2. **Fractional charge quantisation** (demonstrated): Physical quark charges ($+2/3$, $-1/3$) and lepton charges (0, -1) emerge natively when the $U(1)$ charge operator evaluates the constrained low-energy states of the code. Non-physical charges arising in the unconstrained space are projected out by the colour confinement string tension, unifying charge quantisation with confinement as two aspects of a single topological structure.

3. **Gauge–QEC correspondence** (conjectured): The Z-stabilisers of the $[8, 4, 4]$ code provide a discrete structural precursor to continuous $U(1)$ gauge invariance. Charge conservation corresponds to the vacuum projecting phase errors out of the logical subspace.

4. **Maxwell consistency** (verified): The $[8, 4, 4]$ lattice preserves the Bianchi identity and Faraday's Law through the standard plaquette mechanism of lattice gauge theory, confirming the framework's compatibility with classical electrodynamics.

5. **Bare fine-structure constant** (derived): $\alpha_0^{-1} = T(16) + 1 = 137$ from the triangular number of the 16-face bipartite scattering geometry, with no fitted parameters.

Combined with previous derivations of the strong gravity scale, generation hierarchies, and CKM mixing [4, 5], this framework presents a compelling structural foundation for the emergence of the Standard Model gauge sector from the geometry of a single error-correcting code.

Code and Data Availability

The complete Python implementation of all calculations reported in this paper—the O_h projectors, T_{1u} and E_g mass gap analysis, charge operator evaluation, plaquette flux verification, and fine-structure constant derivation—is publicly available at:

`https://github.com/neusym/ckm-lattice`

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