ToCA Electromagnetism v1.0

From Twist to the Periodic Table

ToCA Companion Document — Connects Substrate Twist to Maxwell's Equations and Chemical Structure

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March 2026

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1 Purpose

In ToCA, electromagnetism is not a separate force. It is what twist looks like at macroscopic scales. This document maps the substrate's twist dynamics to Maxwell's equations and shows how the same mechanism that produces electric charge also determines which elements can exist at a given cosmic epoch.

The central claim: **charge is twist, current is twist in motion, and the periodic table is an impedance ladder built from substrate dynamics.**

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2 Charge as Twist

2.1 What twist is

In the FCC substrate, tension can lock in two fundamentally different ways (from the GR Bridge and Physical Substrate documents):

Gradient-locking: Tension locks along a gradient — a directional compression. This produces mass but no charge. It accounts for 11/13 of all locked tension. This is dark matter.

Twist-locking: Tension locks in a rotation — two orthogonal planes twisting against each other. This produces both mass AND charge. It accounts for 2/13 of all locked tension. This is baryonic matter.

A twist has a handedness: it can rotate clockwise or anticlockwise relative to a reference direction. This handedness IS electric charge:

> **Positive charge = clockwise twist (by convention) Negative charge = anticlockwise twist**

Charge conservation ($\sum q = 0$ in closed systems) follows directly from Axiom 3 (tension conservation): every clockwise twist must be balanced by an anticlockwise twist, because the net rotation of a conserved tension field must be zero.

2.2 Why charge is quantised

In a continuous field, twist could take any value. But the FCC substrate is discrete (Axiom 1). A twist involves a finite number of nodes in a finite geometry. The smallest stable twist in the FCC lattice — one that sits in a local minimum of D and resists untwisting — determines the elementary charge e.

Quarks carry fractional charge (+2/3, −1/3) because they are partial twists — configurations involving a subset of the nodes in a proton's 2+1 lock. The proton's total twist is +1 because 2 × (+2/3) + 1 × (−1/3) = +1. The electron's twist is −1: a single, complete anticlockwise twist that compensates the proton.

> **OPEN:** The specific FCC configurations that produce +2/3 and −1/3 twists have not been derived. This requires a detailed analysis of stable twist configurations in the 12-connected lattice.

2.3 Why the electron is 1836 times lighter

The proton is a deep, 3-node locked twist (2+1 configuration). The electron is the substrate's response to the proton's gradient — a compensating twist that is much shallower. It locks less tension because it doesn't need to: it only needs to cancel the charge gradient, not match the proton's structural depth.

The ratio $m_p/m_e = 1836 \approx 6\pi^5$ (within 0.002%) remains unexplained. It likely involves the full dynamic state of the substrate (vibration spectrum, global tension state), not static geometry alone (see Physical Substrate, Section 3).

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3 Electric and Magnetic Fields as Twist Gradients

3.1 Electric field

A stationary charge creates a gradient in the twist field. Nearby regions of the substrate are slightly "pre-twisted" by the presence of the charge. This pre-twist falls off with distance. The electric field E is the gradient of this pre-twist:

> **E = −∇(twist potential)**

In the substrate: $E_i \propto \partial T_{twist} / \partial x_i$, where T_twist is the local twist component of the tension field.

Coulomb's law ($F \propto q_1 q_2/r^2$) follows from the geometry: a twist disturbance in a 3D connected lattice falls off as $1/r^2$ because the "surface area" through which the twist gradient propagates grows as r^2.

3.2 Magnetic field

A moving charge is a twist in motion. The twist propagates through the substrate, creating a rotational pattern in the surrounding tension field. This rotational pattern IS the magnetic field:

> **B = twist in motion**

More precisely: B arises from the curl of the twist current. A stationary twist has no B (no motion, no propagation). A moving twist creates B perpendicular to the direction of motion and perpendicular to E.

This is precisely the Biot-Savart law: $B \propto (v \times \hat{r})/r^2$, where v is the velocity of the charge. The cross product arises because twist is inherently rotational, and its motion creates a perpendicular disturbance.

3.3 Electromagnetic waves

An oscillating twist — a charge that accelerates — creates a propagating disturbance in the substrate's twist field. This disturbance travels at speed c (the substrate's maximum update rate) and carries energy. It IS an electromagnetic wave.

The wave is transverse because twist is perpendicular to the direction of propagation (you can't compress a twist along its own axis — you can only transmit it sideways).

The wave has two polarisations (E and B oscillating in perpendicular planes) because a twist in 3D has two independent rotational degrees of freedom (corresponding to the 2 twist axes in the FCC cell).

> **Light is a twist wave in the substrate. Its speed is $c = l_p/t_p$. Its transverse nature follows from the geometry of twist. Its two polarisations correspond to**

> **the 2 twist axes in the FCC cell.**

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4 Maxwell's Equations in ToCA Language

4.1 The four equations

Maxwell's equations describe how E and B fields are created and how they propagate. In ToCA, each equation has a substrate interpretation:

$\nabla \cdot E = \rho/\varepsilon_0$ (Gauss's law)

The divergence of the twist gradient equals the twist source density. Wherever there is a net twist (charge), the twist field "radiates" outward. This is exactly what a twist in a connected lattice does — it creates an outward gradient.

$\nabla \cdot B = 0$ (No magnetic monopoles)

The divergence of the rotational twist pattern is zero. This follows from the topology of twist: a twist cannot have a "source" in the same way a gradient can. You can't have a point source of rotation — rotation always forms closed loops. In the FCC lattice, this means twist currents always close on themselves.

$\nabla \times E = -\partial B/\partial t$ (Faraday's law)

A changing magnetic field (changing rotational twist pattern) induces a curl in the electric field (creates a twist gradient). In the substrate: when the rotational pattern of twist changes, it forces the surrounding twist gradient to readjust. The curl of the gradient IS that readjustment.

$\nabla \times B = \mu_0 J + \mu_0 \varepsilon_0 \, \partial E/\partial t$ (Ampère-Maxwell)

Twist currents and changing twist gradients both create rotational twist patterns. The displacement current term ($\partial E/\partial t$) means that even without moving charges, a changing twist gradient propagates rotationally. This is what makes electromagnetic waves possible.

4.2 The speed of light

From Maxwell's equations: $c = 1/\sqrt{(\mu_0 \varepsilon_0)}$. In ToCA: c = l_p/t_p. These must be the same, which means:

> **$\mu_0 \varepsilon_0 = t\_p^2/l\_p^2 = 1/c^2$**

This is automatically satisfied by construction. But it tells us something deeper: ε_0 and μ_0 are not independent constants. They are properties of the substrate — ε_0 encodes how easily the substrate accommodates twist gradients (electric permittivity), and μ_0 encodes how easily it accommodates rotational twist patterns (magnetic permeability). Both are determined by the FCC lattice's geometry and the Planck scale.

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5 The Fine Structure Constant

The fine structure constant $\alpha_{em} \approx 1/137.036$ determines the strength of electromagnetic interactions. In ToCA, it should be related to the substrate's twist properties.

What α_em measures: The probability that a twist interaction occurs when two charged configurations are within interaction range. It is the coupling constant between twist-locked tension and the twist field.

In ToCA language: α_em is the ratio of the twist interaction energy to the total tension energy at the Planck scale. It encodes how much of the substrate's total dynamic range is accessible to twist (electromagnetic) interactions.

> **OPEN:** $\alpha_{em} = 1/137.036$ has not been derived from FCC geometry. This is one of the most important open problems in all of physics, not just in ToCA. Any derivation must come from the lattice topology, the twist configuration space, and the global tension state — not from numerology.

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6 S_0 as Impedance and the Periodic Table

6.1 S_0 is impedance

From Core Dynamics: $S_0(n) = f(n) / (1 + D(n))$. This measures how much structure exists relative to how much tension is available. High S_0 = much structure, high resistance to change. Low S_0 = little structure, easy to reconfigure.

In electromagnetic language, this IS impedance: the substrate's resistance to propagating twist signals. High impedance = electromagnetic waves travel slower, interactions are more localised, bound states are deeper. Low impedance = waves travel at full speed, interactions are delocalised, binding is weak.

6.2 The impedance ladder

The periodic table is an impedance ladder. Each element represents a deeper locked configuration that requires more structural support (higher S_0) to exist stably:

Hydrogen (Z=1): Simplest twist-lock. One proton + one electron. Requires minimal S_0. Exists everywhere, always. Most abundant element in the universe. Can form at almost any epoch.

Helium (Z=2): Two protons + two neutrons + two electrons. Requires slightly higher S_0 — enough local tension to force two protons into proximity despite their repulsive twist fields. Forms in Big Bang nucleosynthesis (early, high-D epoch) and in stellar cores.

Carbon, Oxygen (Z=6, 8): Triple-alpha process in stellar cores. Requires *much* higher local S_0 — stellar core temperatures and pressures. Cannot form in the interstellar medium. The universe had to wait billions of years until enough stars had formed to produce these.

Iron (Z=26): End of stellar fusion. Iron is the deepest D-well reachable by normal stellar tension processing. Beyond iron, fusion is endothermic — it costs tension instead of releasing it. Iron is the "floor" of stellar nucleosynthesis.

Uranium (Z=92), Plutonium (Z=94): Require neutron star mergers or supernovae — the most extreme tension events in the universe. These elements exist only because the local impedance (S_0) was temporarily pushed to extreme values by catastrophic events.

6.3 Why the early universe had only H and He

At early times (low n, high D, low f, low S_0): the substrate was hot and fluid. Impedance was low. Twist configurations formed and dissolved rapidly. Only the *simplest* and *deepest* twist-locks survived: hydrogen (trivial) and helium-4 (exceptionally stable due to its doubly-magic nuclear configuration).

Heavier elements require *higher* impedance — more structural support, deeper local D-wells, slower processing. These conditions only arise later, when the substrate has cooled enough (D has fallen enough) for stars to form and provide the necessary local compression.

> **The periodic table is a history book of the substrate's impedance evolution.**

6.4 The connection to S_8 and H_0

S_8 measures clustering amplitude — the pressure that drives structure formation. H_0

measures expansion — the rate at which relaxed tension dilutes. S_0 measures impedance — the substrate's resistance to change.

These three quantities form a triangle:

- **More clustering (higher S_8)** → more pressure → more locking → higher impedance (S_0) → heavier elements possible
- **More expansion (higher H_0)** → more dilution → less clustering → lower impedance → lighter elements favoured
- **Higher impedance (S_0)** → slower processing → slower expansion → indirectly lower H_0

The "potentiometer" from Core Dynamics is this triangle. One knob (the balance between locking, release, expansion, and diffusion) determines all three simultaneously. The position of that knob at any given epoch determines what elements can form.

At the present epoch: $S_8 \approx 0.8$, $H_0 \approx 68$ km/s/Mpc, $S_0 \approx 0.28$. This combination allows everything from hydrogen to uranium — but not all equally easily. The universe is in a sweet spot where the full periodic table is accessible. Earlier, it was too hot (only H, He). Much later, as H_0 continues and S_8 falls, conditions for heavy element formation may become rarer.

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7 Magnetogenesis — Where Cosmic Magnetic Fields Come From

7.1 The twist-fraction model

From Core Dynamics: the substrate's tension has three components — linear mismatch, twist, and frustration. Only twist generates magnetic fields. The twist fraction of total tension varies by environment:

- **Galaxy clusters (violent, merger-dominated):** Twist is a small fraction of total tension (~5%). Linear deformation from shocks dominates. Expected: weak relative B-fields. Observed: B ~ 1–10 μG, u_B/u_thermal ~ 0.003. Consistent.
- **Filaments (quiet, twist-dominated):** Twist is a larger fraction (~30%). Expected: stronger relative B-fields. Observed (Vernstrom et al. 2021): B ~ 30–60 nG in stacked filaments, stronger than standard simulations predict. Consistent.
- **Voids (minimal structure, residual twist):** Almost pure D_floor. Twist from

residual frustration only. Expected: very weak but nonzero fields. Observed: lower limit from Fermi-LAT ($B > 10^{-16}$ G). Awaiting SKA (~2028) for direct measurement.

7.2 The M3 prediction (still valid)

The relative B-field ratio between epochs:

> **$B(z=2) / B(z=0) = \sqrt{(\beta(z=2) / \beta(z=0))}$**

This ratio is independent of absolute field strength and independent of the twist-fraction model. It depends only on how β evolves with redshift. It is testable with SKA.

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8 Open Problems

> **OPEN:** Quark charges (+2/3, −1/3) not derived from FCC twist configurations.

> **OPEN:** α_em = 1/137.036 not derived from lattice geometry.

> **OPEN:** m_p/m_e = 1836 not derived (but $6\pi^5$ noted as suggestive).

> **OPEN:** ε_0 and μ_0 not individually derived from FCC properties (only their product $c^2 = 1/\mu_0\varepsilon_0$ is constrained).

> **OPEN:** The quantitative relationship between S_0 and nuclear binding energies has not been established. The impedance ladder is qualitative, not quantitative.

> **OPEN:** The twist-fraction model for magnetic fields has not been derived from first principles. The environmental dependence (5% in clusters, 30% in filaments) is motivated but not calculated.

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9 Conclusion

Electromagnetism in ToCA is not a separate force bolted onto gravity. It is the twist sector of the same tension field whose gradients produce gravity.

Charge is twist handedness. **Electric fields** are twist gradients. **Magnetic fields** are twist in motion. **Electromagnetic waves** are propagating twist disturbances at speed c. **Maxwell's equations** describe twist dynamics in the substrate.

The periodic table is the impedance ladder of the substrate — each element a deeper locked twist configuration, accessible only when the local impedance (S_0) is high enough. The early universe had low impedance (only H, He). Stars raised the impedance locally. Supernovae and neutron star mergers raised it further. The elements we are made of exist because the substrate's impedance evolved to allow them.

S_0 (impedance), S_8 (clustering/pressure), and H_0 (expansion) form a triangle connected by one dynamical knob — the tension balance of the substrate. One source, one mechanism, one framework.

Electromagnetism is what twist looks like. The periodic table is what impedance allows.