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Gauge Interactions and the Standard Model from the Axioms of Self-Variation Theory

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Abstract

We present an axiomatic framework in which fundamental interactions emerge as necessary consequences of intrinsic self-variation of particle properties, constrained by energy–momentum conservation and causal propagation. Starting from four axioms, we show that Abelian and non-Abelian gauge structures arise naturally. Electromagnetism, Quantum Electrodynamics (QED), Quantum Chromodynamics (QCD), and the electroweak sector are recovered as effective descriptions of underlying self-variation dynamics. Renormalization, confinement, chiral symmetry breaking, and the Higgs mechanism are reinterpreted as geometric and dynamical consequences of self-variation. The Standard Model is thus an effective local limit rather than a fundamental theory.

Keywords: self-variation dynamics; lorentz-covariant transport; abelian and non-abelian gauge theories; spacetime momentum flow; effective standard model; vacuum self-variation; chiral gauge structure; renormalization phenomenology

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1. Introduction

Despite its extraordinary empirical success, the Standard Model (SM) rests on postulated gauge symmetries, coupling constants, and fields whose physical origin remains unexplained [1,2,3]. Gauge invariance, renormalization, confinement, and spontaneous symmetry breaking are introduced as structural principles rather than derived consequences [2].

In this work, we adopt an alternative starting point: intrinsic self-variation of particle properties, consistently constrained by energy–momentum conservation and causal propagation. In this framework, interactions are not fundamental forces but manifestations of spacetime momentum flows that compensate intrinsic self-variation.

We demonstrate that, starting from a set of four axioms, the full gauge structure of the Standard Model emerges naturally.

2. Axiomatic Foundations

Axiom I — Self-Variation

Let q denote a generalized intrinsic property of a material particle, whose specific physical realization may correspond to electric charge, rest mass, or generators of an internal symmetry.

The intrinsic self-variation of q is defined through its spacetime transport and is accompanied by a compensating spacetime effective momentum flow P_μ, according to

$$\partial_\mu q = \frac{b}{\hbar} P_\mu q \quad , \qquad (1)$$

where b is a dimensionless constant and $\hbar$ is the reduced Planck constant.

Equation (1) defines a local and Lorentz-covariant transport law for the intrinsic quantity q, with P_μ acting as an effective spacetime connection-like structure generated by self-variation.

Axiom II — Conservation of Total Momentum

The material particle and the spacetime effective momentum flow form a unified dynamical system (generalized particle). The total four-momentum

$$C_\mu = J_\mu + P_\mu \qquad (2)$$

where J_μ denotes the particle four-momentum, is conserved along the particle worldline,

$$\frac{dC_\mu}{d\tau} = 0, \qquad (3)$$

Equation (3) expresses the exchange of four-momentum between the particle and spacetime along the worldline. Interaction is thus described as momentum transfer within the unified system, rather than as a fundamental force.

Axiom III — Definition of Rest Mass

The invariant rest mass of the generalized system is defined by

$$M^2c^2 = C_\mu C^\mu, \qquad (4)$$

where the Minkowski metric is used to raise the index.

This rest mass is invariant under the local self-variation of P_μ and J_μ, even though these components may vary individually along the particle worldline.

Axiom IV — Causal Propagation via Action Principle

There exists an action functional

$$S[q] = \int L\left(q, \partial_\mu q, P_\mu, J_\mu\right) d^4x, \qquad (5)$$

whose variation with respect to the generalized quantities yields the coupled equations of motion for both the particle and the spacetime momentum flow. This guarantees causal propagation of self-variation through spacetime, while maintaining local Lorentz invariance.

3. Emergence of Abelian Gauge Structure

Defining the spacetime connection

$$A_\mu = \frac{b}{\hbar} P_\mu, \qquad (6)$$

Equation (1) becomes a covariant transport law for the intrinsic quantity q:

$$\partial_\mu q = A_\mu q. \qquad (7)$$

Consistency of mixed derivatives requires the antisymmetric field strength tensor

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu, \qquad (8)$$

which reproduces Maxwell's equations and ensures charge conservation [1]. Gauge transformations naturally arise as local redefinitions of the phase of q,

$$q \to e^{ia(x)} q, \quad A_\mu \to A_\mu + \partial_\mu a(x),$$

leaving (7) and (8) invariant. Quantum Electrodynamics (QED) emerges as the effective quantum description of this Abelian gauge structure.

4. Renormalization as Self-Variation Dynamics

In conventional QED, renormalization compensates ultraviolet divergences arising from point-like fields.

In the self-variation framework, the intrinsic quantities q are dynamically distributed in spacetime via the effective momentum flow P_μ (or equivalently $A_\mu = \frac{b}{\hbar} P_\mu$), which prevents singular self-energies. The running of couplings and vacuum polarization arise naturally from the spacetime evolution of q, without invoking virtual particle creation. Thus, renormalization is

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interpreted as a phenomenological effect of self-variation dynamics, rather than a separate postulate [4].

5. Non-Abelian Generalization and QCD

The intrinsic quantity q is generalized to a vector or matrix in an internal space:

$$q \in \mathbb{C}^N, \quad (9)$$

$$A_\mu = \frac{b}{\hbar} P_\mu^{\text{int}}. \quad (10)$$

The corresponding field strength tensor becomes non-Abelian:

$$F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu + \left[A_\mu, A_\nu\right], \quad (11)$$

reproducing the Yang-Mills structure of QCD [5]. Gauge transformations act as

$$q \to U(x) q, \quad A \to U A_\mu U^{-1} + \left(\partial_\mu U\right) U^{-1}, \quad U(x) \in SU(N),$$

leaving (9)–(11) invariant.

Self-variation requires complete internal momentum balance. Isolated color configurations would generate uncompensated flows and are forbidden, leading naturally to confinement. Stable eigenmodes of the self-variation equations correspond to hadronic states, whose masses are dominated by the spacetime momentum flows.

Confinement

Self-variation requires complete internal momentum balance in the generalized system. Isolated color configurations would generate uncompensated spacetime momentum flows P_μ^{int} (or equivalently A_μ) and are therefore forbidden. Confinement thus emerges naturally as a kinematic consequence of the self-variation dynamics: only color-neutral, globally balanced configurations are allowed [6].

6. Hadron Masses and Spectra

Hadronic states correspond to stable self-variation configurations of the generalized system that satisfy global internal momentum balance.

Their masses are determined by the total spacetime momentum energy of the configuration:

$$m_{hadron}^2 = C_\mu C^\mu = \left(J_\mu + P_\mu^{\text{int}}\right)\left(J^\mu + P^{\mu\ \text{int}}\right), \quad (12)$$

where J_μ is the particle momentum and P_μ^{int} is the compensating internal momentum flow. This explains why hadron masses are dominated by interaction energy (spacetime momentum flows) rather than the quark rest masses [6].

7. Chiral Structure and the Electroweak Sector

Time-oriented self-variation of the intrinsic quantity q breaks left–right symmetry at the fundamental level.

Decomposing q into left- and right-handed components,

$$q_L = \frac{1}{2}\left(1 - \gamma^5\right) q \quad \text{and} \quad q_R = \frac{1}{2}\left(1 + \gamma^5\right) q,$$

the self-variation dynamics naturally lead to a chiral gauge structure for the electroweak interactions:

$$q_L \to U(2)_L \ \textit{doublets}, \quad q_R \to U(1)_Y \ \textit{singlets},$$

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without imposing parity violation by hand [7]. The effective gauge fields A_μ couple differently to left- and right-handed components, reproducing the chiral structure observed in the Standard Model [3].

8. Higgs Phenomenon as Vacuum Self-Variation

Mass generation arises from a stable vacuum configuration of self-variation of the intrinsic quantity q. In this state, the compensating spacetime momentum flows P_μ^{int} (or equivalently the connection

A_μ) acquire persistent non-zero values, corresponding to gauge boson masses:

$$m_A^2 \sim \langle P_\mu^{\text{int}} P^{\mu\ \text{int}} \rangle_{vacuum}.$$

This provides a geometric interpretation of the Higgs mechanism, where masses of the W and Z bosons arise naturally from the vacuum self-variation of the generalized system, without introducing an independent scalar field [8].

9. Fermion Generations and Neutrino Mixing

Multiple stable eigenmodes of the self-variation equation for the intrinsic quantity q naturally correspond to the observed three fermion generations. Each eigenmode represents a distinct stable configuration of q and its associated spacetime momentum flow P_μ^{int}.

Neutrino mixing arises from the non-orthogonality of these self-variation eigenstates:

$$\langle q_i | q_j \rangle \neq 0, \quad i \neq j,$$

which leads to flavor oscillations without introducing additional ad hoc parameters [9].

10. The Standard Model as an Effective Theory

All structural elements of the Standard Model — gauge symmetries, confinement, chiral asymmetry, mass generation, fermion generations, and running couplings — emerge naturally as low-energy manifestations of the self-variation dynamics of the intrinsic quantity q and its associated spacetime momentum flows P_μ^{int}.

In this framework:

Gauge fields

$A_\mu = \frac{b}{\hbar} P_\mu^{\text{int}}$ and their non-Abelian field strengths $F_{\mu\nu}$ arise as effective connections and curvatures.

Chiral asymmetry emerges from time-oriented self-variation.

Gauge boson masses correspond to persistent vacuum momentum flows, giving a geometric Higgs mechanism.

Fermion generations and neutrino mixing correspond to stable eigenmodes of self-variation.

Therefore, the Standard Model is interpreted as an effective, local approximation of the underlying self-variation dynamics, rather than a fundamental theory.

11. Conclusions

This framework provides an axiomatic foundation from which all Standard Model interactions and structures emerge naturally:

Interactions are momentum exchanges compensating intrinsic self-variation, not fundamental forces.

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Gauge symmetries, confinement, and chiral structure are necessary consequences of self-variation dynamics.

Mass generation and Higgs phenomena are geometric and dynamical, arising from persistent vacuum self-variation.

Fermion generations and mixing patterns follow from multiple stable eigenmodes.

By unifying these elements, the approach shows that the Standard Model is a low-energy effective theory, fully consistent with Lorentz covariance, causality, and internal momentum conservation, emerging from four axioms rather than being postulated independently.

Conflict of Interest: The author declares no conflict of interest.

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