Gauge Symmetry Breaking and Topological Charge Quantization in Spiral Time Backgrounds

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Abstract

We propose a modification of standard $U(1)$ gauge theory in which the covariant derivative includes a spiral-time background phase $\phi(t)$, reflecting the informational geometry of the Helix-Light-Vortex (HLV) framework. This structural deformation introduces a geometric contribution to the gauge potential without introducing magnetic monopoles or compactification assumptions. We show that topological charge quantization arises naturally through a modified holonomy condition and argue that the spiral phase causes a symmetry breaking of global $U(1)$ while preserving a local generalized gauge invariance. A corrected expression for the field strength tensor $F_{\mu\nu}^{\text{HLV}}$ is derived and interpreted.

1 Introduction

The HLV theory postulates a spiral time structure $\psi(t) = t + i\phi(t)$ as a fundamental organizing principle of physical information. We aim to explore the implications of embedding this spiral phase $\phi(t)$ into a $U(1)$ gauge theory. In particular, we ask: Can the geometric features of spiral time induce electric charge quantization as a topological effect?

2 Modified Covariant Derivative

We define a modified covariant derivative:

$$D_\mu^{\text{HLV}} = \partial_\mu + ieA_\mu + i\eta\partial_\mu\phi(t) \tag{1}$$

where η is a coupling constant with dimensions of action, and $\phi(t)$ is a differentiable but possibly multi-valued scalar function encoding spiral time.

3 Field Strength Tensor

The field strength tensor is defined via the commutator:

$$\begin{aligned}
[D_\mu^{\text{HLV}}, D_\nu^{\text{HLV}}] &= ie(\partial_\mu A_\nu - \partial_\nu A_\mu) + i\eta[\partial_\mu, \partial_\nu]\phi(t) && (2)\\
&= ieF_{\mu\nu} + i\eta(\partial_\mu\partial_\nu\phi - \partial_\nu\partial_\mu\phi) && (3)\\
&= ieF_{\mu\nu} + 0 && (4)
\end{aligned}$$

Note that the additional term vanishes if $\phi(t)$ is globally smooth and commuting with ∂_μ. However, if ϕ is defined via $\phi(t) = \arg(e^{i\omega t})$, the function is multi-valued and can induce nontrivial contributions under integration.

4 Topological Charge Quantization

We consider a charged particle encircling a loop $\mathcal{C}$ in spacetime. The phase acquired is:

$$\Delta\theta = e \oint_{\mathcal{C}} A_\mu dx^\mu + \eta \oint_{\mathcal{C}} \partial_\mu \phi \, dx^\mu \tag{5}$$

$$= e\Phi + \eta \Delta\phi \tag{6}$$

If $\phi(t)$ is periodic with period T, and $\phi(t) = n\omega t \mod 2\pi$, then:

$$\oint \partial_\mu \phi \, dx^\mu = 2\pi n \tag{7}$$

So the total phase shift becomes:

$$\Delta\theta = e\Phi + 2\pi n \eta \in 2\pi\mathbb{Z} \Rightarrow Q = e + \eta \in \mathbb{Q} \tag{8}$$

Hence, charge appears quantized due to spiral background topology.

5 Symmetry Breaking

The term $\eta\partial_\mu\phi(t)$ breaks global $U(1)$ symmetry, as a constant phase transformation $\psi \to e^{i\alpha}\psi$ leads to a non-invariant action. However, one can define a local transformation:

$$\psi(x) \to e^{i(\alpha + \eta\phi(t))}\psi(x), \quad A_\mu \to A_\mu - \frac{1}{e}\partial_\mu \alpha \tag{9}$$

under which $D_\mu^{\mathrm{HLV}}\psi$ remains form-invariant. Thus, we interpret the symmetry breaking as *structural*, not spontaneous.

6 Conclusion

We have shown that spiral-time-modulated background phases can modify the structure of gauge theory and induce quantization conditions reminiscent of Berry phases or Aharonov-Bohm effects. Charge arises as a geometric holonomy associated with $\phi(t)$, and the $U(1)$ symmetry becomes generalized. Future work will explore non-Abelian extensions and experimental implications.