Section 3. Charge as Phase Orientation (Origin of U(1) Structure)

This section derives electric charge from the phase structure of the CUWF wave field using a sharpened variational and field-theoretic logic. Charge is not assumed as a primitive label. It emerges instead as a topological property of phase transport. Its sign is identified with phase handedness, its conservation follows from continuity and compatibility of phase transport on the entropic manifold, and its quantization arises from winding around topological defects. In this way, an effective U(1) structure appears as a projection of deeper CUWF compatibility conditions rather than as a fundamental axiom.

3.1 Phase orientation as physical handedness (structural vs. redundant phase)

In standard quantum theory, an overall global phase $\exp(i\alpha)$ of a wavefunction is physically redundant because it does not alter measurable probabilities. CUWF accepts this redundancy at the level of simple observables, but draws a stricter conceptual distinction between two very different uses of phase.

- Global redundancy: $\theta(x) \longrightarrow \theta(x) + \alpha$ everywhere. This is a change of description, not a change of physical structure.
- Structural phase orientation: spatial variation of $\theta(x)$, the gradients $\nabla\theta(x)$, and the orientation of phase transport along paths on the entropic manifold.

Within CUWF, only the second level carries direct structural content. Phase gradients represent entropic tension; closed-loop transport of phase encodes topology; and the orientation of such transport defines a binary structural degree of freedom that may be called handedness. Electric charge is therefore not tied to the absolute value of $\theta(x)$, but to the oriented transport of phase. This handedness is well-defined everywhere except at defects, where the topology becomes nontrivial.

3.2 Sign of charge from phase handedness (±): precise definition

Consider a closed loop C encircling a defect. Transport $\theta(x)$ continuously along C and define the orientation of phase rotation by the sign of the line integral of $\nabla\theta$ along that loop:

$$\mathrm{sign}(q) = \mathrm{sign}(\oint_C \nabla\theta \cdot d\ell).$$

If the integral is positive, corresponding to positive phase advance in the chosen orientation convention, the defect is assigned positive charge; if negative, negative charge. This definition is structural rather than particle-label based. Opposite charges correspond to opposite phase-winding classes, and annihilation corresponds to the cancellation of opposite windings around the same defect or defect pair.

3.3 Charge conservation from phase continuity (Noether plus CUWF interpretation)

At the effective level, invariance under continuous phase transformations yields a conserved current j^μ through Noether's theorem. CUWF retains this formal result, but interprets it physically: j^μ represents the flux of phase orientation through the effective spacetime description, and charge conservation reflects continuity of phase transport on the entropic manifold.

On this view, a violation of charge conservation would require either discontinuous phase structure or a failure of compatibility conditions of the type introduced in Section 2. Such breakdowns would carry prohibitive entropic cost. Conservation is therefore not an externally imposed rule. It is a structural consequence of stability.

More precisely, the total charge enclosed in a region V may be written in topological form:

$$Q(V) \propto \oint_{\partial V} \nabla\theta \cdot dS,$$

which remains invariant under smooth deformations of ∂V that do not cross defects. Only nonlocal events such as defect creation, defect annihilation, or topological reconnection can alter Q(V). This is the CUWF reason ordinary local dynamics conserve charge.

3.4 Quantization: charge as winding number (topological invariant)

Charge quantization follows from the single-valuedness of $\Psi(x)$ away from defects. For a loop C that encircles a defect,

$$q \propto n = (1 / 2\pi) \oint_C \nabla\theta \cdot d\ell,$$

where $n \in \mathbb{Z}$ is the winding number. The integer character of n is not optional. If n were non-integer, then $\Psi(x) = A(x)\exp(i\theta(x))$ would fail to return to the same structural value after one complete loop, making the configuration multi-valued and therefore incompatible with stable persistence. Quantization is thus not an added postulate, but a direct consequence of phase continuity together with discrete topological anchors.

Distinct integers n define distinct topological charge classes. Transitions between such classes require defect creation, annihilation, or the crossing of an entropic stability barrier. This gives a structural account of why charge is robust.

3.5 Coulomb-like interaction from the entropic cost of phase gradients (variational derivation)

To formalize this account, assume a minimal local entropic cost functional:

$$E[\theta] = (\kappa / 2) \int |\nabla\theta(x)|^2 \, d^3x,$$

where κ is an entropic stiffness parameter. This functional plays a role analogous to elastic energy in a continuous medium: configurations with sharper phase gradients carry greater structural cost.

3.5.1 Euler–Lagrange field equation

Varying $E[\theta]$ with respect to θ gives

$$\delta E = \kappa \int \nabla\theta \cdot \nabla(\delta\theta) \, d^3x.$$

Integrating by parts and neglecting boundary terms yields

$$\delta E = -\kappa \int (\nabla^2\theta) \, \delta\theta \, d^3x.$$

Requiring $\delta E = 0$ for arbitrary $\delta\theta$ gives the Euler–Lagrange equation away from defects:

$$\nabla^2\theta = 0.$$

Thus, in defect-free regions, the phase satisfies Laplace's equation. Nontrivial structure enters only through localized topological anchors.

3.5.2 Defects as effective sources (bridge to Poisson form)

When a defect is present, compatibility fails locally and the effective field equation acquires a source term representing the topological anchor:

$$\nabla^2\theta = s(x),$$

where s(x) encodes the structural content of the defect, such as its winding class. The exact distributional form of s(x) may be treated in the Appendix; for the purposes of the main text, it is enough to regard it as localized support for the topology.

3.5.3 Mapping to electrostatics (Poisson and Gauss)

Define an effective scalar potential ϕ proportional to the phase and an effective charge density ρ proportional to the defect source:

$$\phi \equiv \alpha\theta, \quad \rho \equiv \beta s(x),$$

for constants α and β that fix units. The field equation then takes Poisson form:

$$\nabla^2\phi = \rho.$$

Defining an effective electric field $E \equiv -\nabla\phi$ yields

$$\nabla \cdot E = \rho,$$

which is Gauss's law in differential form. Electrostatics thus emerges as an effective projection of phase compatibility conditions on the entropic manifold.

3.6 Coulomb scaling and physical interpretation

For an isolated defect of winding number n, symmetry implies a radially symmetric solution of $\nabla^2\theta = 0$ outside the defect together with the boundary condition $\oint_C \nabla\theta \cdot d\ell = 2\pi n$. The resulting solution scales as $|\nabla\theta(r)| \approx n/r$. Substituting this scaling into $E[\theta]$ shows that the interaction energy between defects acquires the familiar 1/r dependence associated with Coulomb behavior.

This result rests on three transparent assumptions: large-scale isotropy of the entropic manifold, locality of the cost functional, and the absence of strong long-range screening. At the effective level, the theory reproduces the familiar picture of electric fields sourced by charge. Ontologically, however, CUWF interprets electromagnetism not as a fundamentally independent interaction added to matter, but as the large-scale relaxation pattern of entropic structure driven by phase compatibility and topological winding.