The Holographic Circlette: Part XIV Electromagnetic Dipole Radiation and Isospin Breaking in the Meson Sector

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Abstract

We derive the electromagnetic mass splitting of the pion multiplet from the geometric boundary conditions of the discrete 4.8.8 tensor network. While the internal self-energy of static point-defects (baryons) is governed by discrete lattice graph combinatorics, we demonstrate that mesons act as oscillating quantum dipoles whose electromagnetic fields are unconfined. Consequently, virtual photons mediating the meson's electromagnetic self-energy must radiate into the emergent 3+1D continuum. The geometric path of least action for this unconfined 3D flux forms a semicircle, inducing a strict $\pi/2$ path-length penalty relative to the confined 1D strong force bridge. Applying this continuous geometric factor to the fundamental algorithmic bit-weight yields an exact mass-squared splitting of $\Delta m^2 = \frac{\pi}{2}\alpha\Lambda_{\text{QCD}}^2$. This predicts a charged pion mass splitting of 4.56 MeV, in exceptional agreement with the experimental value of 4.59 MeV, natively reproducing Dashen's Theorem with zero free parameters.

1 Introduction: The Dichotomy of Confinement

In Part XI of this series, the electromagnetic mass splittings of the baryon octet were derived using universal lattice coefficients (A and B). These coefficients were calculated under the strict condition that baryons are static, localized distance-1 topological defects.

However, applying these static graph-theoretic coefficients to the meson sector yields physically incorrect results, notably predicting the neutral pion to be heavier than the charged pion. This failure is a fundamental physical necessity. Unlike baryons, mesons are dynamically oscillating phase-slips spanning a 1-dimensional gauge bridge. More importantly, evaluating the electromagnetic self-energy of a meson requires respecting the absolute geometric dichotomy between the strong and electromagnetic interactions at the discrete-to-continuum boundary.

The strong force is topologically confined. The color flux connecting the q and $\bar{q}$ constituents is strictly forbidden from radiating into the emergent 3D vacuum, forcing it to traverse the shortest possible discrete path: the 1D square gauge bridge of length d.

Conversely, the electromagnetic force is unconfined. The virtual photons mediating the electromagnetic self-energy of the $q\bar{q}$ dipole are free to radiate outward from the 2D lattice boundary into the emergent 3+1D continuous spacetime. Therefore, the electromagnetic self-energy of a meson cannot be evaluated using discrete 2D graph routing; it must be evaluated using the continuous 3D geometry of the emergent vacuum.

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2 The Bowed Flux Line and the $\pi/2$ Penalty

When an oscillating dipole situated on a 2D planar boundary radiates an unconfined Coulomb field into an emergent 3D half-space, the primary field lines connecting the two constituent charges do not travel in a straight 1D line. Instead, the field lines bow outward into the extra spatial dimension.

Geometrically, the lowest-order continuum field line connecting two points separated by a distance d through an emergent extra dimension forms a perfect semicircle. The path length of this semicircular arc is given by:

$$L_{\text{arc}} = \pi \left(\frac{d}{2}\right) = \frac{\pi}{2} d \tag{1}$$

In our discrete framework, the algorithmic string tension ($w = \alpha \Lambda_{\text{QCD}}$) dictates the absolute energy cost per unit of topological distance. Because the confined strong interaction traverses the strict 1D bridge, its interaction distance is $d = 1$, incurring a baseline algorithmic penalty proportional to w.

However, because the unconfined virtual photon must traverse the bowed semicircular path through the 3D continuum, its effective path length is exactly $\pi/2$ times longer. Consequently, the effective electromagnetic string tension for the dipole is strictly inflated by this exact continuous geometric ratio:

$$\text{Effective EM Penalty} = \frac{\pi}{2} w \tag{2}$$

3 Dashen's Theorem on the Discrete Lattice

Because mesons are relativistic quantum oscillators spanning the gauge bridge, their dynamic interaction must be evaluated in the mass-squared (m^2) channel. The energy perturbation is defined as the product of the interaction penalty and the absolute structural scale of the bridge (Λ_{QCD}).

For the neutral pion (π^0), the internal charge configuration ($(u\bar{u} - d\bar{d})/\sqrt{2}$) dynamically cancels, yielding no macroscopic dipole moment. Consequently, it emits no semicircular electromagnetic flux into the 3D bulk, and its electromagnetic mass-squared shift is exactly zero at leading order.

Conversely, the charged pion ($\pi^\pm$) acts as a macroscopic $u\bar{d}$ dipole. Its virtual photon exchange is forced to take the bowed semicircular path through the 3D continuum. The resulting mass-squared splitting is therefore entirely electromagnetic, natively satisfying Dashen's Theorem:

$$\Delta m^2 = m_{\pi^\pm}^2 - m_{\pi^0}^2 = \left(\frac{\pi}{2} w\right) \Lambda_{\text{QCD}} \tag{3}$$

Substituting the fundamental definition of the algorithmic bit-weight ($w = \alpha \Lambda_{\text{QCD}}$), the relation simplifies to a purely fundamental topological invariant:

$$\Delta m^2 = \frac{\pi}{2} \alpha \Lambda_{\text{QCD}}^2 \tag{4}$$

4 Numerical Evaluation

We evaluate this zero-parameter relation using the rigorously established lattice constants: the fundamental confinement scale ($\Lambda_{\text{QCD}} = 332$ MeV) and the bare algorithmic bit-weight ($w = 2.4227$ MeV).

The predicted electromagnetic mass-squared splitting is:

$$\Delta m^2 = \frac{\pi}{2} (2.4227 \text{ MeV})(332 \text{ MeV}) = 1263.4 \text{ MeV}^2 \tag{5}$$

Applying this squared shift to the isospin-averaged multiplet mass yields a predicted linear mass splitting of approximately 4.56 MeV. This result matches the experimental pion splitting of 4.59 MeV to an accuracy of 0.6%, entirely driven by the transition from discrete 1D confinement to continuous 3D unconfined radiation.