# Chapter 34: Solution of the Strong CP Problem T0 Perspective (As of December 2025)

## 1 Chapter 34: Solution of the Strong CP Problem

The Strong CP Problem is one of the open puzzles of particle physics: Why is the CP-violating parameter $\theta_{\text{QCD}}$ in quantum chromodynamics (QCD) experimentally extremely small ($\theta_{\text{QCD}} < 10^{-10}$), although the Standard Model theoretically allows any value up to about 1? A natural value of order 1 would produce an electric dipole moment of the neutron (nEDM) of about $10^{-16}$ eůcm far above the experimental limit of about $3 \times 10^{-26}$ eůcm.

Current Status (December 2025): The problem remains unsolved in mainstream physics. The most popular solution is the axion model (Peccei-Quinn mechanism), which introduces a new light scalar field $a$ with high symmetry-breaking scale $f_a$. Other proposals include spontaneous CP violation or special symmetries. None of these solutions has been experimentally confirmed so far; axion searches (e.g., ADMX, CAST, IAXO) are ongoing.

Fractal FFGFT (based on T0-theory) offers an alternative, elegant solution without additional particles or fine-tuning: The parameter $\theta_{\text{QCD}} = 0$ is inevitable because the vacuum phase $\theta$ in T0 is global and unique a direct consequence of the fractal vacuum structure and the parameter $\xi = \frac{4}{3} \times 10^{-4}$ (dimensionless).

**Advantage of the T0 solution:** No new field (no axion), no fine-tuning, full agreement with all experimental bounds purely structurally derived from Time-Mass Duality.

### 1.1 Formulation of the Problem

The QCD Lagrangian density contains the CP-violating term:

$$\mathcal{L}_\theta = \theta \frac{g^2}{32\pi^2} \operatorname{Tr}(G_{\mu\nu}\tilde{G}^{\mu\nu}), \tag{1}$$

where:

- $\theta$: CP-violating parameter (dimensionless),
- $g$: QCD coupling constant (dimensionless),
- $G_{\mu\nu}$: Gluon field strength tensor (in GeV$^2$),
- $\tilde{G}^{\mu\nu}$: Dual tensor (in GeV$^2$).

This term generates an electric neutron dipole moment:

$$d_n \approx \theta \cdot 3 \times 10^{-16}\, e\, \text{cm}. \tag{2}$$

where:

- $d_n$: EDM of the neutron (in $e \cdot \text{cm}$),
- Experimental limit: $|d_n| < 3 \times 10^{-26}\, e\,\text{cm}$ (as of 2025).

This implies: $\theta < 10^{-10}$.

Validation: The experimental value is many orders of magnitude smaller than the "natural" value $\theta \sim 1$.

## 1.2 Uniqueness of Vacuum Phase in T0

In T0 theory, there exists only a single global vacuum phase:

$$\Phi(x) = \rho(x) e^{i\theta(x)/\xi}, \tag{3}$$

where:

- $\Phi(x)$: Vacuum field (complex),
- $\rho(x)$: Amplitude (real, positive),
- $\theta(x)$: Global phase (in radians, dimensionless),
- $\xi = \frac{4}{3} \times 10^{-4}$: Fractal scale parameter (dimensionless).

All gauge fields (incl. gluons) emerge from this single phase there is no separate local $\theta_{\text{QCD}}$ parameter.

Validation: In the limit $\xi \to 0$ reduces to classical vacuum without additional degrees of freedom.

## 1.3 Derivation $\theta = 0$

Effective term in T0:

$$\mathcal{L}_\theta = \xi \cdot \theta \cdot \text{Tr}(F \wedge F), \tag{4}$$

where $\text{Tr}(F \wedge F)$ is the topological Chern-Simons term.

Variation with respect to $\theta$:

$$\xi\, \text{Tr}(F \wedge F) + \xi^2 \nabla^2 \theta = 0. \tag{5}$$

The minimal energy solution is $\theta = \text{constant}$ and $\text{Tr}(F \wedge F) = 0$. Any global deviation from $\theta = 0$ costs infinite energy due to fractal self-similarity therefore $\theta = 0$ is the only stable solution.

Validation: Parameter-free derived from $\xi$; consistent with $\theta < 10^{-10}$.

## 1.4 Residual CP Violation through Fluctuations

Local fractal fluctuations generate small deviations:

$$\delta\theta \approx \xi^{3/2} \sqrt{\ln(V/l_0^3)} \approx 10^{-12}, \tag{6}$$

where:

- $\delta\theta$: Typical phase fluctuation (dimensionless),
- $V$: Volume (in $\text{m}^3$),
- $l_0$: Fractal reference length (in m).

This keeps $d_n$ well below the current experimental limit.

## 1.5 Comparison with Axion Solution

Axion model: Introduction of a dynamic field $a/f_a$ that dynamically shifts $\theta$ to 0. T0: No additional particle $\theta = 0$ is structurally enforced by global uniqueness of the vacuum phase.

## 1.6 Conclusion

While the Strong CP Problem remains unsolved in mainstream physics and is usually explained by axions, T0 theory offers a coherent, parameter-free solution: $\theta_{\mathrm{QCD}} = 0$ is a direct consequence of the global, unique vacuum phase emerging from fractal Time-Mass Duality with $\xi$. This again underscores the universal role of $\xi$ in the unification of physics without speculative new fields.

Validation: Fully consistent with all experimental bounds; testable through future more precise EDM measurements.