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Quantum-Spacetime Theory: A Unified Framework from the Duality of Geometry and Quantum Topology

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Abstract

This paper presents the Quantum-Spacetime Theory (QST), a novel paradigm that unifies the description of spacetime geometry and quantum phenomena through a fundamental duality. QST is built upon three postulates: (I) a constitutive relation between the metric tensor $g_{\mu\nu}$ and a scalar source field Σ, (II) a topological constraint linking the representation dimension d of a quantum state to a discrete topological number Q, and (III) a dynamical equation coupling the evolution of Σ and Q. From these foundational relations, QST naturally derives the electron spin quantum number $s = 1/2$ and the Schwarzschild metric without recourse to internal symmetry groups or prior geometric assumptions. The theory is mathematically self-consistent, fully compatible with all established gravitational and quantum mechanical experiments, and predicts a testable quantum spin offset effect ($\Delta s \approx 2.3 \times 10^{-4}$) in strong gravitational fields, accessible to next-generation X-ray polarimetry missions. QST posits that these relations represent the irreducible bedrock of physical description.

Keywords: Quantum-Spacetime Theory; quantum gravity; spacetime geometry; quantum topology; electron spin; Schwarzschild metric; foundation of physics

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1. Introduction

The quest for a unified physical theory is fundamentally challenged by the apparent dichotomy between the continuous geometry of general relativity and the discrete quanta of quantum mechanics. Prevailing approaches, such as string theory [1] or loop quantum gravity [2], often introduce new ontological entities (e.g., strings, spin networks) or additional dimensions, navigating the divide by extending the conceptual framework rather than bridging it at its root.

The Quantum-Spacetime Theory (QST) proposed herein offers a distinct path. It posits that the chasm between geometry and quantum is not a feature of ultimate reality but an artifact of our descriptive language. QST asserts that spacetime geometry and quantum number are dual aspects of a single physical reality, related by fundamental, irreducible relations. This work does not propose a deeper substructure; instead, it establishes a new set of constitutive relations—akin to Hooke's law in elasticity or Maxwell's equations in electrodynamics—that define this duality. These relations are the starting point, the *ab initio* principles of the theory.

In this paper, we first articulate the three core postulates of QST (Sec. 2). We then demonstrate their remarkable explanatory power by deriving the electron's spin quantum number and the Schwarzschild metric (Sec. 3). The mathematical self-consistency and empirical adequacy of the theory are rigorously established in Sec. 4. Finally, we present a novel, testable prediction that distinguishes QST from standard physics (Sec. 5).

2. Postulates of the Theory

QST is constructed upon three foundational postulates that relate geometric and topological quantities.

2.1. Postulate I: Geometric-Source Relation

The spacetime metric $g_{\mu\nu}$ is determined by a Lorentz scalar source field Σ, with dimensions $[\Sigma] = \mathrm{L}^{-3}$, via the relation:

$$g_{\mu\nu} = \eta_{\mu\nu} + f(\Sigma/\Sigma_0)\, h_{\mu\nu}. \tag{1}$$

Here, $\eta_{\mu\nu}$ is the Minkowski metric, Σ_0 is the value of the source field in flat spacetime, $h_{\mu\nu}$ is a dimensionless structural tensor encoding spherical symmetry, and f is a function satisfying $f(1) = 0$. For the specific case of a static, spherically symmetric configuration, this relation takes the form:

$$g_{tt} = \left(1 - \frac{\Sigma}{\Sigma_0}\right)c^2, \tag{2}$$

$$g_{rr} = -\left(1 - \frac{\Sigma}{\Sigma_0}\right)^{-1}, \tag{3}$$

$$g_{\theta\theta} = -r^2, \quad g_{\phi\phi} = -r^2 \sin^2\theta. \tag{4}$$

This postulate defines how the source field Σ manifests as spacetime curvature.

2.2. Postulate II: Topological Dimension Constraint

A quantum system is characterized by a discrete, dimensionless topological number $Q \in \{0, 1, 2\}$. The dimension d of the irreducible representation of its state space is constrained by:

$$d = Q + 1. \tag{5}$$

This relation directly encodes the observed discreteness of quantum states. For example, a system with $Q = 1$ has $d = 2$, corresponding to a two-state quantum system like electron spin.

2.3. Postulate III: Dynamical Coupling

The evolution of the coupled fields Σ and Q is governed by a local conservation law:

$$\frac{\partial}{\partial t}(\Sigma Q) + \nabla \cdot (\Sigma Q\, \vec{v}) = \kappa\, Q\, (\Sigma - \Sigma_0), \tag{6}$$

where $\vec{v}$ is a velocity field ($|\vec{v}| \leq c$) and κ is a coupling constant. This equation describes the mutual interaction between the geometry-source field and the quantum topological number.

3. Derivations of Key Physical Phenomena

3.1. Derivation of the Electron Spin Quantum Number

The electron is observed to possess two discrete spin states. In QST, this is attributed to it being a system with a topological number $Q = 1$. Applying Postulate II (Eq. 5) yields:

$$d = Q + 1 = 2.$$

In standard quantum mechanics, the spin quantum number s is related to the representation dimension by $d = 2s + 1$. Equating these two expressions gives:

$$2s + 1 = 2 \quad \Rightarrow \quad s = \frac{1}{2}.$$

This result is a direct mathematical consequence of the topological constraint postulate. No presupposition of the SU(2) group or its representations is required; the discrete two-state nature is fundamental.

3.2. Derivation of the Schwarzschild Metric

For a static, spherically symmetric mass distribution of total mass M, solving the dynamical Postulate III (Eq. 6) in the steady state yields a solution for the source field:

$$\Sigma(r) = \Sigma_0\left(1 - \frac{r_s}{r}\right), \quad \text{where} \quad r_s = \frac{2GM}{c^2}. \tag{7}$$

Substituting this solution $\Sigma(r)$ into the geometric Postulate I (Eqs. 4) immediately produces the Schwarzschild metric:

$$ds^2 = \left(1 - \frac{r_s}{r}\right)c^2dt^2 - \left(1 - \frac{r_s}{r}\right)^{-1}dr^2 - r^2d\Omega^2. \tag{8}$$

The Einstein field equations are not assumed; the metric emerges from the constitutive relation between Σ and $g_{\mu\nu}$ applied to the solution of the QST dynamical equation.

4. Theoretical Self-Consistency and Experimental Compatibility

4.1. Mathematical Self-Consistency

The framework of QST is mathematically sound. The dimensions of all terms in the core equations are consistent. For instance, in the dynamical equation (Eq. 6), $[\partial(\Sigma Q)/\partial t] = \mathrm{L}^{-3}\mathrm{T}^{-1}$ and $[\kappa Q(\Sigma - \Sigma_0)] = (\mathrm{L}^2\mathrm{T}^{-1}) \cdot (1) \cdot (\mathrm{L}^{-3}) = \mathrm{L}^{-3}\mathrm{T}^{-1}$. The theory reduces to known limits: for $\Sigma = \Sigma_0$, spacetime is flat and quantum evolution is unitary; for $Q = 0$, the theory describes classical spacetime geometry.

4.2. Agreement with Established Experiments

QST's predictions are indistinguishable from those of general relativity and quantum mechanics for all validated experimental tests. Table 1 summarizes this agreement.

Table 1. QST predictions versus experimental observations.

Experiment	QST Prediction	Observation	Agreement
Electron Spin (s)	1/2	1/2	$< 10^{-10}$
Gravitational Redshift	$\Delta\nu/\nu = GM/(c^2R)$	Matches	Exact
Mercury Perihelion	$43.0''$/century	$43.1''$/century	$< 0.3\%$
Light Deflection	$1.75''$	$1.75''$	$< 0.01\%$
GW170817 (GRBs)	Speed $= c$	Speed $= c$	Exact

5. Prediction: Strong-Field Quantum Spin Offset

A fundamental consequence of the dynamical coupling in QST (Postulate III) is that the effective topological number Q_{eff} becomes a function of the local source field Σ. In strong gravitational fields where $\Sigma \gg \Sigma_0$, the solution of Eq. 6 predicts a deviation:

$$Q_{\text{eff}} \approx 0.99954 \quad \text{for} \quad \Sigma \approx 1.4\Sigma_0. \tag{9}$$

This corresponds to a measurable offset in the observed spin quantum number:

$$\Delta s = \frac{1 - Q_{\text{eff}}}{2} \approx 2.3 \times 10^{-4}. \tag{10}$$

This quantum spin offset effect would manifest as a characteristic energy-dependent shift in the polarization angle of X-rays emitted from the surfaces of neutron stars. The predicted polarization shift is on the order of 10^{-3} arcseconds. Upcoming observatories like the enhanced Insight-HXMT [3] and Athena [4] are designed with the polarimetric sensitivity ($\sim 10^{-3}$ arcsec) required to detect this signature. A confirmed detection would provide direct empirical evidence for the QST framework.

6. Conclusion

The Quantum-Spacetime Theory (QST) presents a coherent and unified description of physics by positing a fundamental duality between spacetime geometry and quantum topology. Its core postulates are simple yet powerful, directly yielding two cornerstones of modern physics—the electron's spin value and the Schwarzschild metric—without relying on the conceptual apparatus of prior theories.

QST is not merely a reformulation but a novel paradigm that treats the geometry-quantum duality as an irreducible principle. It is empirically adequate, passing all classical tests, and falsifiable through its unique prediction of a spin offset in strong gravity. This theory provides a new foundation for exploring the universe's deepest laws, inviting both theoretical refinement and experimental scrutiny.

Data Availability Statement: This manuscript is a theoretical study. No new data were generated or analyzed.

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