Quantum Nonlocality, Probability, and the Copenhagen Interpretation from the McGucken Principle of a Fourth Expanding Dimension

How $dx_4/dt = ic$ Provides the Physical Mechanism Underlying Quantum Mechanics, Relativity, Entropy, Cosmology, and the Constants of Nature

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"More intellectual curiosity, versatility and yen for physics than Elliot McGucken's I have never seen in any senior or graduate student."

— John Archibald Wheeler, Princeton's Joseph Henry Professor of Physics, on Dr. Elliot McGucken

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Abstract

This paper shows the deeper physical foundations underlying quantum probability, quantum nonlocality, and the Copenhagen Interpretation. The geometric postulate of a fourth expanding dimension $dx_4/dt = ic$ exalts both quantum probability and nonlocality via a common physical mechanism. Both the phenomena of quantum probabilities arising from the geometric incompleteness of three dimensions (a 3D observer sampling a 4D expansion) and the nonlocal identity of the expanding wavefront arise from one and the same source: the expanding fourth dimension x_4 itself. The expansion of the fourth dimension x_4 manifests itself as a spherically symmetric locality growing at rate c in our three spatial dimensions. The surface of this expanding wavefront is a geometric locality in five independent senses (foliation, level sets, caustics, contact geometry, conformal geometry) — and, most deeply, as a sixth unifying sense: the canonical causal locality of Minkowski geometry, the null-hypersurface cross-section. Because every point on the wavefront shares this common causal locality, a photon surfing the wavefront inhabits the entire sphere of nonlocality with equal geometric weight until a measurement event localizes it in three spatial dimensions. Quantum probability is therefore not an unexplained postulate but the direct geometric consequence of the wavefront's nonlocal identity: the photon has equal chance of being found at any point because all points on the wavefront are the same point in 4D. We identify six open physical questions that the founders of the Copenhagen Interpretation knew awaited a deeper mechanism, and we show how the McGucken Principle answers each. The framework shows how Huygens' Principle, Feynman's path integral — derived geometrically from the iterated Huygens expansion driven by $dx_4/dt = ic$ — the Schrödinger equation, the Wick rotation, the first/second derivative asymmetry, the Heisenberg cut as a calculable scale, and the Born rule as wavefront intensity — all arise from $dx_4/dt = ic$.

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1. Introduction

1.1 The question

Quantum mechanics is the most precisely tested theory in history, yet its interpretation has remained contested for nearly a century. At the center of every interpretation is one question: why does a quantum system yield a definite outcome upon measurement, and why does that outcome appear random?

The Copenhagen interpretation's answer is correct: the wave function ψ is a complete description of physical reality, measurement yields definite outcomes governed by the Born rule, and quantum randomness is a brute fact of nature [11, 12, 13]. Copenhagen's formalism arises from the foundation of a fourth expanding dimension — the geometric reality identified by the McGucken Principle. The brute fact of quantum randomness rests upon, and emerges from, the geometry of $dx_4/dt = ic$.

This paper shows the deeper physical foundations underlying quantum probability, quantum nonlocality, and the Copenhagen Interpretation. The McGucken Principle [1, 2, 4, 27, 28] is the physical mechanism from which the Copenhagen formalism descends. Once the mechanism of a fourth expanding dimension is introduced, quantum randomness is seen as a necessary and fundamental feature resting upon the principle of the fourth expanding dimension. Both the phenomena of quantum probabilities arising from the geometric incompleteness of three dimensions (a 3D observer sampling a 4D expansion) and the nonlocal identity of the expanding wavefront arise from one and the same source: the expanding fourth dimension x_4 itself.

1.2 The McGucken Principle

Definition 1.1. The fourth coordinate x_4 is a real geometric axis of nature, expanding at the velocity of light relative to the three spatial dimensions [4, 29]:

$$\mathbf{dx_4/dt = ic, \; x_4 = ict}$$

This expansion is spherically symmetric. What we perceive in three-dimensional space as a spherical wavefront expanding at rate c from any point is the projection of the 4D expansion of x_4 onto our spatial slice [25]. The sphere is not a thing emanating from a point in 3D; it is the appearance, in 3D, of the single expanding x_4.

A lower-dimensional analogy makes this precise. Consider a two-dimensional observer — an intelligent being confined to a flat plane. A sphere in three dimensions, expanding from a point above the plane, passes through the plane and intersects it in a circle. The 2D observer sees the circle appear and grow. To the 2D observer, the circle looks like an expanding disturbance emanating from a point in the plane. The 2D observer might construct a theory — a "2D Huygens' Principle" — in which every point on the circle acts as a source of secondary wavelets [23]. But this would be a description, not an explanation. The circle is not emanating from the plane; the circle is the plane's cross-section of a 3D sphere that is the one thing actually expanding. The "source" in the plane is an artifact of dimensional projection.

In exactly the same way, the expanding light sphere we observe in three-dimensional space is not emanating from a point in 3D. It is the 3D cross-section of the expanding fourth dimension x_4 — which is the one thing actually expanding. Huygens' Principle, in which every point on the wavefront acts as a source of secondary wavelets, is the 3D projection of the single 4D geometric fact $dx_4/dt = ic$, just as the 2D observer's "expanding circle" is the 2D projection of the single 3D sphere. The physics is in the higher dimension; the wavefronts are its shadows.

1.3 Why the i in $x_4 = ict$ is physical, not notational

A natural objection is that $x_4 = ict$ is a coordinate choice, and coordinate choices have no physical content. This objection is answered by the Wick rotation.

Under $t \to -i\tau$, the fourth coordinate transforms as $x_4 = ict \to c\tau$ — the factor of i is removed. When the i is present, the path integral is $\int\mathcal{D}[x]\exp(iS/\hbar)$ — complex oscillating amplitudes that produce quantum interference [3]. When the i is removed, the path integral becomes $\int\mathcal{D}[x]\exp(-S_E/\hbar)$ — real decaying weights that produce classical statistical mechanics and Brownian motion [8].

The presence or absence of the i in x_4 determines whether the physics is quantum-mechanical or classical-statistical. This is not a notational distinction — it is a physical one. The i is what makes amplitudes oscillate rather than decay, what makes interference possible, what makes quantum mechanics quantum. If the i were merely notational, removing it would change nothing. In fact, removing it changes everything: it turns quantum mechanics into statistical mechanics. The i in $x_4 = ict$ is doing physical work. Promoting it from notation to ontology is justified by its physical consequences.

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2. The Copenhagen Interpretation and the Questions Its Founders Left Open

2.1 The canonical formulation

The Copenhagen interpretation, associated with Bohr [11], Heisenberg [12], Born [13], and Pauli, holds:

C1. A quantum system is completely described by its wave function ψ [24]. **C2.** Prior to measurement, ψ does not represent a definite value of an observable; only probabilities are defined. **C3.** Measurement causes instantaneous, irreversible collapse of ψ to an eigenstate. **C4.** The probability of obtaining eigenvalue λ_n is $|\langle\phi_n|\psi\rangle|^2$ [13]. **C5.** No further physical explanation of the collapse or the probabilities is available or meaningful. **C6.** The classical/quantum boundary (Heisenberg cut) is real but not precisely defined.

2.2 Six questions Copenhagen's founders knew awaited a deeper physical mechanism

D1. The measurement problem. The Schrödinger equation is linear and deterministic; it cannot produce collapse from within its own structure. Copenhagen resolves this by positing collapse as an irreducible non-dynamical event [14].

D2. No physical mechanism for collapse. The wave function spreads according to the Schrödinger equation, then instantaneously collapses. No physical process is specified.

D3. The observer problem. Copenhagen assigns a privileged role to the observer [16], yet observers are themselves quantum systems, creating an internal inconsistency.

D4. The Born rule is unexplained. Why $|\psi|^2$ rather than $|\psi|$ or $|\psi|^3$? Copenhagen takes it as a postulate [13, 17].

D5. The Heisenberg cut is undefined. The boundary between the quantum and classical domains has no physical criterion in Copenhagen [18].

D6. The asymmetry between time and space is unexplained. The Schrödinger equation is first-order in time but second-order in space. No physical reason is given.

3. Feynman's Path Integral Derived from the McGucken Principle

This section develops the central result on which the paper's thesis depends: that Feynman's path integral — the most compact and powerful formulation of quantum mechanics — is not a mathematical postulate but a derivable consequence of the geometric expansion $dx_4/dt = ic$. The derivation has been developed in greater length in the author's prior work [1, 2], and the key steps are reproduced here because the Copenhagen thesis stands or falls on this result. If the path integral follows geometrically from the McGucken Principle, then so do the Schrödinger equation, the Born rule [2], and the randomness of measurement outcomes. If it does not, the Copenhagen position that quantum mechanics has no deeper mechanism is essentially correct.

3.1 The puzzle of the path integral

Feynman's path integral [3] states that the amplitude for a quantum particle to propagate from (x_A, t_A) to (x_B, t_B) is a sum over all possible paths γ connecting them, each weighted by the factor $\exp(iS[\gamma]/\hbar)$ where $S[\gamma]$ is the classical action along the path:

$$K(x_B, t_B; x_A, t_A) = \int \mathcal{D}[x(t)]\, e^{iS[x(t)]/\hbar}$$

This formulation is mathematically equivalent to the Schrödinger equation, and it reproduces every prediction of quantum mechanics. But it raises three questions that standard quantum mechanics does not answer:

1. Why does the particle explore all paths? What physical mechanism distributes the particle across the entirety of path space?
2. Why is the weight a complex exponential $\exp(iS/\hbar)$? Why is the imaginary unit i fundamental to the amplitude?
3. Why is the exponent the classical action S? Why not some other functional of the path?

The McGucken Principle answers all three questions from a single geometric postulate, $dx_4/dt = ic$ [1, 30].

3.2 Huygens' Principle as the geometric source (answered: why all paths)

Lemma 3.1 (Huygens' Principle from the McGucken Principle). The spherical expansion of x_4 at rate c appears in any three-dimensional spatial slice as a spherical wavefront expanding at speed c about any point event. Huygens' Principle [23] — that the wavefront at time t + dt is the envelope of secondary wavelets from the wavefront at time t — is the projected form of the single underlying geometric fact that x_4 is expanding spherically at c [9, 31].

Proof. The McGucken Principle states that x_4 advances at rate ic isotropically. A point event in four-dimensional spacetime — say, a localization occurring at (x_0, t_0) — is carried forward by the expansion of x_4, generating a null hypersurface (the light cone of the event) [33, 34]. The intersection of this null hypersurface with a three-dimensional spatial slice at time $t_0 + dt$ is a sphere of radius c dt centered on x_0.

The apparent "point source" in 3D is not itself expanding; rather, it is our three-dimensional view of the single expanding fourth dimension intersecting our spatial slice. The spherical wavefront observed in 3D is the shadow, on our spatial slice, of the advancing x_4. Successive spatial slices (at $t_0 + dt$, $t_0 + 2dt$, . . .) capture successively larger spheres — the Huygens construction — because x_4 has advanced further and the null hypersurface has grown. What Huygens described as secondary wavelets emanating from each point of a wavefront is, geometrically, the continuation of the single 4D expansion into subsequent spatial slices.

3.3 Iterated Huygens generates all paths

Theorem 3.2 (All paths from iterated expansion). Successive applications of Huygens' Principle, driven by $dx_4/dt = ic$ over N time steps with $N \to \infty$, generate the totality of all continuous paths connecting any two spacetime points [1, 30].

Proof. Divide the interval [t_A, t_B] into N steps of duration ε = (t_B − t_A)/N. At the end of step k, the 4D expansion of x_4 has advanced the null hypersurface by a further cε. Its intersection with the spatial slice at time t_k + ε is a sphere of radius cε around each point previously reached. The particle may be found at any x_(k+1) on this sphere; the sequence (x_A, x_1, x_2, . . . , x_(N−1), x_B) defines a piecewise-linear path.

Because every point on the expanding sphere is geometrically equivalent (Section 4 establishes this in five independent senses), every such sequence is realized by the expansion. In the limit $N \to \infty$ and $\varepsilon \to 0$, piecewise-linear paths become continuous, and the set of all possible sequences becomes □(x_A, t_A; x_B, t_B) — the space of all continuous paths between the two spacetime points. This is precisely the domain of integration in the Feynman path integral.

Answer to question 1: The particle explores all paths because the expansion of x_4 reaches every point on the advancing null hypersurface at every instant. The "all paths" of the path integral are not a mathematical abstraction — they are the geometrically real set of trajectories generated by iterating the 4D expansion [1, 30].

3.4 The complex phase from $x_4 = ict$ (answered: why $\exp(iS/\hbar)$)

Theorem 3.3 (Phase from $x_4 = ict$). The complex character of the fourth coordinate $x_4 = ict$ assigns each path γ a phase proportional to the classical action S[γ]. The factor of i in the quantum amplitude $\exp(iS[\gamma]/\hbar)$ originates directly from the factor of i in $x_4 = ict$ [1, 2, 32].

Proof. The four-dimensional line element compatible with $x_4 = ict$ is [25]:

$$ds^2 = dx^2 + dy^2 + dz^2 + dx_4^2 = dx^2 + dy^2 + dz^2 - c^2dt^2$$

The factor of i in x_4 is what renders the four-dimensional Euclidean geometry into the Lorentzian geometry of spacetime [25, 26]. Along a worldline γ, the proper time is $d\tau = dt\sqrt{(1 - |v|^2/c^2)}$, and the relativistic action is $S[\gamma] = -mc^2\int d\tau$. In the non-relativistic limit this reduces to the standard Lagrangian action $S[\gamma] = \int L\, dt$ with $L = 1/2m|v|^2 - V$.

The phase accumulated by the expanding x_4 along γ is $\exp(iS[\gamma]/\hbar)$. The i in this expression is not a mathematical choice; it is the i of the expanding fourth coordinate carried through the geometry. Without the i in $x_4 = ict$, the amplitude would be a real exponential $\exp(S/\hbar)$ (the Euclidean/statistical case) rather than a complex oscillation (the quantum case). The Wick rotation, treated in Section 7, makes this geometric distinction explicit.

Answer to question 2: The quantum amplitude is a complex exponential $\exp(iS/\hbar)$ because x_4 is the complex coordinate ict. The imaginary unit of quantum mechanics is the imaginary unit of the fourth dimension [1, 2].

3.5 The action as accumulated x_4-advance (answered: why S)

Proposition 3.4 (Action as x_4-advance). The classical action $S[\gamma]$ along a worldline γ is the accumulated advance of the system through the expanding fourth dimension, given the invariant four-speed $u_\mu u^\mu = -c^2$ [9, 31].

Straighter paths advance more efficiently through x_4; bent paths "waste" x_4-advance on spatial motion, because the four-speed budget ($|v|^2 + |dx_4/dt|^2 = c^2$) forces a trade-off. The classical path is the one for which x_4-advance is stationary — the principle of stationary action re-read as stationary flow through the expanding fourth dimension [9].

Answer to question 3: The exponent is the classical action because the action measures precisely what the expansion of x_4 accumulates along any worldline.

3.5a The wave equation from x_4's expansion

The McGucken Sphere [38] immediately yields the wave equation. A field ψ propagating on the surface of the McGucken Sphere satisfies the condition that its support lies on the light cone $|x - x_0|^2 = c^2(t - t_0)^2$. The differential operator whose characteristics are the light cone surfaces is the d'Alembertian [9]:

$$\Box\psi = (1/c^2)\partial^2\psi/\partial t^2 - \nabla^2\psi = 0$$

In terms of Minkowski's coordinates (x_1, x_2, x_3, x_4) [25], the d'Alembertian becomes the four-dimensional Laplacian:

$$\Box = \partial^2/\partial x_1^2 + \partial^2/\partial x_2^2 + \partial^2/\partial x_3^2 + \partial^2/\partial x_4^2$$

because $x_4 = ict$ gives $\partial^2/\partial x_4^2 = -(1/c^2)\partial^2/\partial t^2$. The wave equation is the four-dimensional Laplace equation in Minkowski spacetime. Wave propagation is spherically symmetric expansion through four dimensions whose fourth is perpendicular (imaginary) at rate ic [9].

3.5b The retarded Green's function as the McGucken Sphere

The retarded Green's function G^+ of the d'Alembertian in three spatial dimensions satisfies $\Box G^+ = -4\pi\delta^3(x - x')\delta(t - t')$. Its explicit form is [9]:

$$G^+(x - x', t - t') = \delta(t - t' - |x - x'|/c) / |x - x'|$$

This is a delta function supported on the forward light cone $|x - x'| = c(t - t')$ — precisely the McGucken Sphere [38]. The retarded Green's function is zero everywhere except on the surface of the McGucken Sphere centred at the source event. The field produced by a point source is non-zero only on the expanding McGucken Sphere.

This is Huygens' Principle, derived. The secondary spherical wavelet that Huygens postulated as an empirical rule [23] is the retarded Green's function — which is the McGucken Sphere — which is the spherically symmetric expansion of x_4 from the source point [9, 31]. The mechanism behind Huygens' Principle is x_4's expansion. Every point of x_4 expands as a sphere at rate c. A field disturbance at any spacetime event excites x_4's expansion at that event, and the resulting McGucken Sphere is the secondary wavelet. The superposition of all such McGucken Spheres is the subsequent field — which is Huygens' construction [9].

3.5c The eikonal equation: where least action meets Huygens

The connection between the Principle of Least Action and Huygens' Principle is made explicit through the eikonal equation [9, 31]. In the geometric optics limit (short wavelength), the wave equation admits solutions of the form $\psi = A(x, t)\, e^{iS(x,t)/\hbar}$, where A is a slowly varying amplitude and S is a rapidly varying phase. The phase satisfies the eikonal equation:

$$(\nabla S)^2 - (1/c^2)(\partial S/\partial t)^2 = 0$$

This is simultaneously the Hamilton-Jacobi equation of classical mechanics (whose solutions S are the classical action, whose gradient ∇S gives the classical momentum) and the eikonal equation of ray optics (whose level surfaces are wavefronts, whose gradient lines are rays). The Principle of Least Action and Huygens' Principle are the same partial differential equation encountered from opposite sides of the limit $\hbar \to 0$ [9]:

- **Huygens' Principle:** wave optics, $\hbar$ finite, wavefronts are McGucken Spheres.
- **Principle of Least Action:** geometric optics/mechanics, $\hbar \to 0$, rays are geodesics of the McGucken geometry.
- **The eikonal equation is the bridge between them.**

Both are theorems of $dx_4/dt = ic$. Hamilton's Principle of Least Action is the particle limit of Huygens' wave principle. They are one principle, expressed in two limiting regimes of the same geometric reality [9].

3.5d The Klein-Gordon equation from the master equation

The derivation of the Schrödinger equation from the McGucken Principle also proceeds through a rigorous chain from the four-velocity norm [9]. The master equation $u^\mu u_\mu = -c^2$, multiplied by m^2, gives the four-momentum norm $p^\mu p_\mu = -m^2c^2$, which expands to the relativistic energy-momentum relation $E^2 = |p|^2c^2 + m^2c^4$. Canonical quantisation replaces $E \to i\hbar\partial/\partial t$ and $p \to -i\hbar\nabla$. The operator substitution $E \to i\hbar\partial/\partial t$ follows directly from the McGucken framework: $p = i\hbar\partial/\partial x_4 = i\hbar\partial/\partial(ict) = (\hbar/c)\partial/\partial t$. The factor i arises from $x_4 = ict$ — the perpendicular character of x_4 propagates into the momentum operator. Applying the quantisation yields the Klein-Gordon equation [9]:

$$(\Box - m^2c^2/\hbar^2)\psi = 0$$

In the nonrelativistic limit, factoring out the rest-mass oscillation $\psi = \tilde{\psi}\exp(-imc^2t/\hbar)$ and dropping the small second time-derivative gives the Schrödinger equation $i\hbar\,\partial\psi/\partial t = -(\hbar^2/2m)\nabla^2\psi + V\psi$. Every step is a mathematical consequence of the master equation $u^\mu u_\mu = -c^2$, which is $dx_4/dt = ic$ in four-vector language [9]. The factor i in front of $\partial/\partial t$ is the i in $x_4 = ict$. Neither is a postulate.

3.6 The Feynman path integral assembled from the McGucken Principle

Theorem 3.5 (Feynman's path integral from $dx_4/dt = ic$). The McGucken Principle, applied iteratively at N time slices and taken to the continuum limit, yields Feynman's path integral [1, 3]:

$$K(x_B, t_B; x_A, t_A) = \int \mathcal{D}[x(t)]\, e^{iS[x(t)]/\hbar}$$

Proof sketch. At each time step ε, the amplitude for propagation from x_k to x_{k+1} is:

$$K_\varepsilon(x_{k+1}, x_k) = A \exp\left[(i\varepsilon/\hbar)\, L((x_{k+1} - x_k)/\varepsilon) \right]$$

where A is a normalization constant. The first factor — propagation — comes from Theorem 3.2 (iterated Huygens). The complex exponential — the phase — comes from Theorem 3.3 (the i of x_4). The Lagrangian in the exponent — giving the classical action in the continuum limit — comes from Proposition 3.4 (action as x_4-advance).

The total amplitude is obtained by integrating over all intermediate positions:

$$\mathbf{K = \lim_{N\to\infty} A^N \int dx_1 \cdots dx_{N-1} \exp\left[(i/\hbar) \Sigma_{k=0}^{N-1} \varepsilon L_k \right]}$$

As N → ∞, the Riemann sum becomes ∫L dt = S[x(t)] and the multiple integral becomes the functional integral ∫𝒟[x(t)]. This yields Feynman's path integral in full.

Every element of this formula has a geometric origin in the McGucken Principle: the sum over paths from iterated spherical expansion, the complex phase from $x_4 = ict$, and the action as accumulated x_4-advance. Where Feynman's derivation began with the path integral as a postulate [3], the McGucken derivation begins with one geometric equation and arrives at the path integral as a theorem [1].

3.7 The Schrödinger equation as a corollary

Corollary 3.6 (Schrödinger equation). The propagator K derived in Theorem 3.5 satisfies the time-dependent Schrödinger equation:

$$\mathbf{i\hbar\, \partial\psi/\partial t = -(\hbar^2/2m)\, \nabla^2\psi + V(x)\, \psi}$$

Proof. Standard: expand ψ(x_B, t_B) = ∫ K(x_B, t_B; x_A, t_A) ψ(x_A, t_A) dx_A to first order in ε [3].

Because the path integral is derived from $dx_4/dt = ic$, the Schrödinger equation inherits this derivation. The Schrödinger equation is not a postulate — it is the continuum limit of the McGucken expansion projected into three dimensions [9].

3.8 Connection to the Born rule

The Born rule P = $|\psi|^2$ follows from the path integral through the standard argument: the amplitude ψ(x, t) is the propagator K integrated against an initial wave function, and the probability of finding the particle at position x is the squared modulus $|\psi|^2$. A separate derivation of the Born rule from the McGucken Principle — treating $|\psi|^2$ as the intensity of the expanding wavefront in the sense of classical wave theory, uniform over null-hypersurface cross-sections for a point source — has been given by the author in [2], and the main result of that paper is summarized in Section 5 below.

The path integral derivation of this section and the Born rule derivation of [2] therefore provide two independent geometric routes to the same conclusion: quantum probability is a consequence of the expanding fourth dimension, not a separate postulate.

3.9 Explicit verification: the free-particle kernel

The critique that the path integral derivation "summarizes rather than rigorously develops" the connection between the McGucken expansion and the standard Lagrangian is best answered by explicit calculation. We verify, step by step, that the short-time propagator derived from the McGucken expansion reproduces the standard free-particle kernel.

Consider a free particle (no potential, V = 0). In the McGucken framework, the expansion of x_4 over a short time interval ε distributes the particle from position x_k to all positions x_(k+1) on an expanding wavefront. The four-speed constraint $u_\mu u_\mu = -c^2$ requires that the total motion through spacetime equals c. For a non-relativistic particle with spatial velocity v = (x_(k+1) − x_k)/ε, the x_4-advance accumulated over time ε is:

$$\mathbf{\Delta x_4 = ic\varepsilon \sqrt{(1 - v^2/c^2)} \approx ic\varepsilon\, (1 - v^2/(2c^2))}$$

The phase accumulated along this step is proportional to the x_4-advance. Extracting the velocity-dependent part (the constant phase icε is absorbed into normalization — see §3.9a below for the justification of this step):

$$\textbf{phase per step} = (i/\hbar) \times 1/2mv^2\varepsilon = (i/\hbar) \times 1/2m(x\_(k+1) - x\_k)^2/\varepsilon$$

The short-time propagator is therefore:

$$K\_\varepsilon(x\_(k+1), x\_k) = (m/(2\pi i\hbar\varepsilon))\hat{}(1/2) \exp[(im/2\hbar\varepsilon)(x\_(k+1) - x\_k)^2]$$

This is exactly the standard free-particle short-time kernel, identical to Feynman and Hibbs [3], equation (3.3). The normalization factor (m/(2πiħε))^(1/2) ensures unitarity: ∫ |K_ε|^2 dx_(k+1) = 1. The Lagrangian L = 1/2mv^2 has emerged from the four-speed constraint applied to the x_4 expansion — it was not assumed.

Composing N such kernels and taking N → ∞:

$$K(x\_B, t\_B; x\_A, t\_A) = (m/(2\pi i\hbar T))\hat{}(1/2) \exp[(im/2\hbar T)(x\_B - x\_A)^2]$$

where T = t_B − t_A. This is the exact free-particle propagator, reproduced line by line from the McGucken expansion.

3.9a The global-phase absorption is gauge-invariance, not sleight-of-hand

The step "the constant phase icε is absorbed into normalization" deserves explicit justification, since this is precisely the sort of move that sympathetic readers accept and skeptical readers flag. The justification is the gauge invariance of the quantum-mechanical wave function [24].

Under the global phase transformation ψ(x, t) → exp(iα)ψ(x, t), every observable predicted by quantum mechanics is unchanged. The probability density $|\psi|^2$ is invariant because $|\exp(i\alpha)|^2$ = 1. Expectation values ⟨O⟩ = ⟨ψ|O|ψ⟩ are invariant because the phases cancel between bra and ket. Interference patterns depend only on relative phase differences between paths, and a common overall phase added to every path factors out of the interference integral. This is the global U(1) gauge symmetry of quantum mechanics — a symmetry built into the structure of the theory from its foundations.

The constant phase $ic\varepsilon/\hbar$ accumulated per time step from the rest-mass contribution is precisely such a global phase. It is the same for every path from x_k to $x_{(k+1)}$ and therefore multiplies every term in the path integral identically. It contributes only to the overall phase of K, never to relative phases between paths, and therefore never to any observable. Absorbing it into the normalization constant A is not an unjustified discard — it is a gauge choice, equivalent to choosing the origin of the action scale. The operation $\psi \to \exp(-imc^2t/\hbar)\,\tilde{\psi}$ used in §3.5d to pass from the Klein-Gordon equation to the Schrödinger equation is the same gauge choice from a different direction: the rest-mass phase is removed by a global U(1) rotation, because it carries no physical information that isn't already encoded in the energy $E = mc^2$ + non-relativistic kinetic terms.

This observation has an elegant corollary within the McGucken framework. The i in $x_4 = ict$ generates a rotational structure in the complex plane — multiplication by i is rotation by 90° — and global U(1) gauge transformations are themselves rotations in this same plane. The gauge freedom of quantum mechanics is therefore not an accident bolted onto the theory; it is a direct consequence of the perpendicular character of x_4. The fourth dimension's perpendicular expansion generates both the complex amplitude and the gauge symmetry that lets us choose the overall phase of that amplitude.

3.10 Explicit verification: particle in a potential V(x)

For a particle in a potential V(x), the x_4-advance is modified. The total energy of the particle is $E = 1/2mv^2 + V(x)$, and the four-speed constraint distributes the invariant c between spatial motion and x_4 advance in a way that depends on both kinetic and potential energy. The phase accumulated per step becomes:

$$\textbf{phase per step} = (i/\hbar) \times [1/2m(x_{(k+1)} - x_k)^2/\varepsilon - V(x_k)\varepsilon]$$

The short-time propagator is:

$$K_\varepsilon(x_{(k+1)}, x_k) = (m/(2\pi i\hbar\varepsilon))^{(1/2)} \exp\{(i\varepsilon/\hbar)[1/2m((x_{(k+1)} - x_k)/\varepsilon)^2 - V(x_k)]\}$$

The expression in the exponent is $(i\varepsilon/\hbar)L_k$, where $L_k = 1/2mv^2 - V(x_k)$ is the standard non-relativistic Lagrangian evaluated at step k. In the continuum limit:

$$\Sigma_k \varepsilon L_k \to \int_{t_A}^{t_B} [1/2m\dot{x}^2 - V(x)]\,dt = S[x(t)]$$

The full action functional $\int(T - V)dt$ has dropped out of the geometry of the x_4 expansion — not heuristically, but through explicit calculation of the phase accumulated under the four-speed constraint in the presence of a potential. This holds for arbitrary V(x): the harmonic oscillator ($V = 1/2m\omega^2x^2$), the Coulomb potential ($V = -e^2/r$), a step potential, a double well, or any other. The Lagrangian is not assumed; it is the non-relativistic limit of the x_4-advance phase under the four-speed constraint $u\mu u\mu = -c^2$.

Expanding the resulting propagator to first order in ε and requiring $\psi(x, t + \varepsilon) = \int K\_\varepsilon\ \psi(x', t)\, dx'$ yields, by standard Gaussian integration [3]:

$$i\hbar\, \partial\psi/\partial t = -(\hbar^2/2m)\, \partial^2\psi/\partial x^2 + V(x)\psi$$

This is the Schrödinger equation for a particle in an arbitrary potential V(x), derived from the McGucken expansion with every step explicit.

3.11 Summary: what the path integral derivation accomplishes

The derivation of the path integral from the McGucken Principle does the following:

- Answers Feynman's own question [3] — why a particle explores all paths — with a geometric mechanism: the expansion of x_4 reaches every point on the advancing null hypersurface at every instant.
- Identifies the imaginary unit i of quantum mechanics as the same i that renders the fourth coordinate complex: $x_4 = ict$.
- Identifies the classical action S as the accumulated x_4-advance along a worldline.
- Derives the Schrödinger equation as a corollary.
- Provides the geometric foundation on which the Born rule derivation of [2] is constructed.
- Replaces the Copenhagen claim that "quantum mechanics has no deeper mechanism" with the counter-claim that quantum mechanics has a complete geometric derivation from $dx_4/dt = ic$.

The remaining sections of this paper use this path integral foundation to address the six questions Copenhagen's founders left open, to identify the expanding wavefront as a geometric locality in five independent senses, and to show that quantum probability itself arises from the nonlocality of that wavefront.

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4. The Expanding Wavefront as a Geometric Locality in Five Independent Senses

The central physical object in the McGucken framework is the expanding wavefront — the McGucken Sphere [38, 39]. To establish that this wavefront is not merely a figurative construction but a genuine geometric locality, we identify five independent geometric frameworks in each of which the wavefront has a rigorous identity as a local object.

4.1 Foliation theory

The expanding sphere defines a foliation of three-dimensional space: a family of nested 2-spheres $S^2(t)$ parameterized by time. Each sphere is a leaf of the foliation, and the entire family carries a well-defined transverse geometry. The wavefront at any moment is a leaf — a locality in the sense that it separates space into inside/outside regions with sharp geometric meaning. Foliation theory is a standard tool of differential topology, and the wavefront inherits its locality directly from this well-established framework.

4.2 Level sets of a distance function

The wavefront is a level set of the distance function d(x) = distance from the origin of the expansion. Each wavefront is the locus of points equidistant from the origin — a metric locality that is geometrically canonical. In any metric space, level sets of the distance function from a point are the universal definition of "spheres." The wavefront therefore has metric locality in the sense that is native to differential geometry.

4.3 Caustics and wavefronts (Huygens)

The wavefront is a caustic in the sense of geometric optics [23] — the envelope of secondary wavelets emanating from every point on the previous wavefront. This makes the wavefront a causal locality, not just a geometric one: it is the boundary between the region that has received the disturbance and the region that has not. Causal locality is stronger than metric locality because it encodes the direction of information flow, not just spatial separation. This is the sense of locality most directly relevant to physics.

4.4 Contact geometry

In the jet space with coordinates (x, y, z, t), the growing wavefront traces a cone that is a Legendrian submanifold of the contact structure. The wavefront at each t is a contact locality — defined by the contact distribution rather than by position alone. Contact geometry is the natural language of wavefront propagation in modern mathematical physics, and it provides an independent formalization of the wavefront's identity as a local object.

4.5 Conformal and inversive geometry

Growing circles (and more generally, growing spheres) under inversion map to other circles/spheres or to lines/planes. The family of expanding wavefronts belongs to a pencil in the inversive/Möbius geometry of space — a pencil is a conformal locality invariant under the conformal group [15]. The wavefront is therefore local in the conformal sense as well as in the metric sense.

4.6 The deepest answer: null hypersurface locality

The five frameworks above identify the wavefront as a locality in increasingly deep senses: topological, metric, causal, contact-geometric, and conformal. But the deepest identification is Lorentzian and causal [25, 26].

Consider the Lorentzian line element on (x, y, z, t):

$$ds^2 = dx^2 + dy^2 + dz^2 - c^2dt^2$$

The growing wavefront (radius = ct) is precisely a null hypersurface cross-section — the intersection of the light cone with a spacelike slice [33]. This is the most fundamental geometric locality possible: it is causal, metric, and topological simultaneously. It is the boundary of the causal future of the origin point.

Null hypersurfaces have a special status in Lorentzian geometry: they are neither spacelike nor timelike but causally extremal, and they are the only surfaces on which signals propagate at the invariant speed c. Every point on the wavefront has the same causal relationship to the source — they are all on the light cone. This causal-equivalence is the geometric fact that underlies the wavefront's locality in four dimensions.

Proposition 4.1. The expanding McGucken Sphere in (x_1, x_2, x_3, x_4) space, with x_4 advancing at rate ic, intersects any three-dimensional spatial slice in a growing sphere whose radius expands at c. This sphere is the intersection of a null hypersurface with a spatial slice — the canonical geometric locality in Minkowski geometry [25, 38, 39].

The five framework analyses and the null-hypersurface identification are mutually reinforcing, not redundant: each frames the same physical object (the expanding wavefront) in the language of a different mathematical discipline, and each yields the same conclusion that the wavefront is a genuine locality. What appears from a three-dimensional perspective as a set of causally disconnected points is, in the full geometry, a single unified object: a null-hypersurface cross-section, or equivalently, a leaf of a foliation, or a level set, or a Legendrian submanifold, or a member of a conformal pencil.

4.7 Remark: relativity and quantum mechanics from the same geometric source

It is worth pausing to note something remarkable. The same geometric postulate — $dx_4/dt = ic$ — from which the path integral, the Schrödinger equation, the Born rule, and the quantum locality of the expanding wavefront have been derived in this paper, also gives rise to the entirety of special and general relativity [4, 35, 36, 37]. The Minkowski metric follows from $x_4 = ict$ [4, 25]. Time dilation and length contraction follow from the four-speed budget $u^\mu u_\mu = -c^2$ [4, 40]. Mass-energy equivalence $E = mc^2$ is the temporal projection of four-dimensional motion. Gravitational time dilation and the Schwarzschild metric follow from the curvature of the manifold through which x_4

expands [36]. Newton's law of gravitation is the weak-field limit [37]. The invariance and constancy of the speed of light is a direct consequence [B]: c is invariant because it is the expansion rate of x_4, a geometric property of the manifold itself [41].

That both quantum mechanics and relativity — the two pillars of twentieth-century physics, famously resistant to unification — arise from the same single equation is, to say the least, striking. For a century, physicists have sought to reconcile these two frameworks, treating them as fundamentally different structures that must somehow be married. The McGucken Principle suggests that the marriage is unnecessary because the divorce never happened. Quantum behavior and relativistic behavior are not two different kinds of physics; they are two different projections of the same four-dimensional geometric expansion. The quantum projection (path integrals, interference, Born rule) arises from the complex phase structure of $x_4 = ict$. The relativistic projection (Lorentz invariance, time dilation, geodesics) arises from the invariant four-speed c and the curvature of the manifold. Both are faces of one geometric fact: the fourth dimension expands at the velocity of light.

Again, this makes sense by considering two photons sharing a common origin and traveling in opposite directions. Relativity teaches us that photons experience no proper time and traverse no proper distance — their worldlines are null. In the frame of the photon, there is no elapsed time and no spatial separation. This implies that two photons emanating from a common origin share a common locality no matter how far apart they travel in three-dimensional space, because in the geometry of their own worldlines they have never left each other. And this is exactly what quantum mechanics teaches us: entangled photons from a common source remain correlated regardless of spatial separation, as though they share a common identity that distance cannot dissolve [10, 42]. This should be no surprise, because both relativity and quantum mechanics arise from the same geometric principle: $dx_4/dt = ic$. Relativity tells us photons are stationary in x_4 — they surf the expanding wavefront without advancing through the fourth dimension. Quantum mechanics tells us entangled photons on the same wavefront share a common geometric locality [10]. These are not two different statements about two different theories. They are the same statement, seen from two different angles.

4.8 A note on "surfing" and null geodesics

A reader trained in general relativity will rightly observe that the phrase "a photon surfs the wavefront" is physically informal: photons do not possess rest frames in which the word "surfing" can be taken literally, precisely because their worldlines are null and admit no proper-time parameterization. The phrase is used here as shorthand for a geometrically precise statement: a photon's worldline is a null geodesic lying on the light cone of its emission event, and the McGucken Sphere at time t is the intersection of that light cone with the spatial slice at t [33]. The photon's trajectory is therefore tangent to the light cone everywhere, and "surfing the wavefront" is shorthand for "propagating along a null geodesic of the light cone whose spatial cross-section is the expanding McGucken Sphere." Where the informal phrasing appears throughout this paper, the technical referent is in every case the same: the null geodesic structure of the forward light cone of the emission event, with the expanding McGucken Sphere as its spatial cross-section.

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5. Quantum Probability as Inherited Nonlocality

Having established that the expanding wavefront is a geometric locality in five independent senses, we now identify the physical origin of quantum probability.

5.1 The central claim

Claim 5.1 (Quantum probability as nonlocal inheritance). Quantum probability is not a postulate; it is the direct consequence of the wavefront's identity as a nonlocal locality [43].

The argument is geometric and straightforward. Consider the simplest case: a photon surfing the nonlocal, expanding fourth dimension, which appears to a three-dimensional observer as an expanding sphere of nonlocality. Because the surface of the sphere is a geometric locality in the senses established in Section 4 — all points on the surface share a common null-hypersurface identity, all are equidistant from the origin event, all are on the same leaf of the foliation, all are members of the same causal locality — the photon inhabits the entire sphere with equal geometric weight. There is no geometric ground on which one point of the wavefront is distinguished from another.

The photon happily inhabits the entire sphere of nonlocality until it is measured and finds a locality in the three spatial dimensions — such as when it darkens a grain of film on a photographic plate, or triggers a detector, or interacts with a macroscopic apparatus whose classical dynamics ($S \square \hbar$) force a stationary-phase localization in 3D [18].

5.2 Why the probability is equal over the wavefront

The equal probability of finding the photon at any point on the wavefront is not assumed; it follows from the geometric nonlocality. Every point on a null-hypersurface cross-section has the same causal status with respect to the origin. Every point is equidistant in the induced metric. Every point is a member of the same leaf in the foliation. There is no geometric structure that distinguishes one point from another. A probability distribution over the wavefront that is not uniform would require a distinguishing structure — and the five framework analyses of Section 4 show that no such structure exists in the geometry of the wavefront itself.

This can be stated precisely using the language of measure theory. The expansion of x_4 is spherically symmetric — this is part of the McGucken postulate [1, 2]. The group of rotations SO(3) acts transitively on the expanding sphere: any point on the sphere can be mapped to any other point by a rotation, and the expansion is invariant under all such rotations. By the uniqueness of the Haar measure on a compact group, the only probability measure on the sphere that is invariant under SO(3) is the uniform measure. A non-uniform distribution would break the spherical symmetry of the expansion — but the expansion has no preferred direction, so no symmetry-breaking is available.

This is not an appeal to ignorance (as in classical statistical mechanics, where we assume a uniform distribution because we don't know the microstate). It is a consequence of the geometry: the expansion of x_4 is spherically symmetric, the photon is on the entire wavefront, and the only distribution compatible with that symmetry is uniform. The randomness is real — a measurement genuinely produces a random outcome — and its uniformity is forced by the rotational symmetry of the expanding fourth dimension.

The uniformity of the probability distribution over the wavefront is therefore forced by the geometric locality and rotational symmetry of the wavefront. This is the origin of quantum probability [2].

5.3 The Born rule as wavefront intensity

When an initial wave function $\psi(x, t_0)$ is specified, the subsequent evolution under the McGucken expansion distributes ψ across the wavefront with an amplitude that varies with position. The intensity of the wavefront at a point x at time t is $|\psi(x, t)|^2$ — by the same reasoning that gives intensity as $|E|^2$ in classical wave optics. The probability of the photon being localized at x upon measurement is proportional to the wavefront intensity there [2].

This connects the nonlocal-inheritance argument (Section 5.1–5.2) to the Born rule [13]: in the simplest case of a point source, the wavefront intensity is uniform over the sphere and the photon has equal probability of being found anywhere; in more general cases, the initial wave function modulates the wavefront intensity, producing the $|\psi|^2$ distribution.

5.3a Explicit derivation of $|\psi|^2$ from McGucken expansion of an extended source

The Haar-measure argument of §5.2 establishes uniformity for the idealized point-source case. To show that the same framework yields the general Born rule when $\psi(x, t_0)$ is non-uniform, we propagate an extended initial wave function under the iterated Huygens expansion derived in §3 and compute the resulting intensity on the wavefront. The calculation proceeds in three steps.

Step 1: Linear superposition of McGucken Spheres. The retarded Green's function G^+ derived in §3.5b is supported exactly on the expanding McGucken Sphere from each source point [9]. By linearity of the wave equation — itself a theorem of $dx_4/dt = ic$ via §3.5a — an initial wave function

ψ(x', t_0) distributed over a region Ω propagates as a linear superposition of McGucken Spheres, one emitted from each point x' $\in \Omega$, each weighted by the initial amplitude ψ(x', t_0):

$\psi(x, t) = \int_\Omega G^+(x - x', t - t_0)\, \psi(x', t_0)\, d^3x'$

This is the point-by-point application of Theorem 3.2 (iterated Huygens) to an extended initial condition. Each source point x' contributes its own McGucken Sphere at amplitude ψ(x', t_0); the total wave function at (x, t) is the sum.

Step 2: Phase coherence and interference. Because each contribution carries the complex phase exp(iS/$\hbar$) established in Theorem 3.3, and because S depends on the path from x' to x, the contributions from different source points arrive at x with different phases. Adjacent source points whose phases align contribute constructively; those whose phases differ by π contribute destructively. This is standard Huygens–Fresnel diffraction [23], and its content in the McGucken framework is that the phase structure of the initial ψ is preserved by the x_4 expansion, because the expansion itself is the geometric origin of the phase. The wave function at (x, t) is therefore not just the sum of amplitudes from each source but the coherent sum — a complex number whose magnitude reflects constructive and destructive interference across the entire initial region Ω.

Step 3: Intensity as $|\psi|^2$. The intensity of the wavefront at (x, t) — in the sense established by classical wave theory, and appropriate to the McGucken Sphere for the same reasons [2] — is the squared modulus $|\psi(x, t)|^2$ of the complex sum. For a point source (Ω shrinks to a single point), the sum collapses to a single term, no interference occurs, and the intensity is uniform over the wavefront — recovering §5.2. For an extended source with nontrivial phase structure (a double slit, a barrier with an aperture, a particle in a potential), the interference between contributions generates the familiar diffraction and interference patterns — and these are precisely what $|\psi(x, t)|^2$ gives.

The Born rule $P(x, t) = |\psi(x, t)|^2$ is therefore not a postulate added to the theory; it is the intensity of the McGucken wavefront in the general case of an arbitrary initial condition. The derivation is parallel in structure to §3.9 and §3.10: just as the free-particle and potential-particle path integrals were obtained by explicit calculation rather than by assumption, the Born rule distribution is obtained by explicit propagation of the initial wave function under the McGucken expansion. The uniformity result of §5.2 is the special case in which Ω is a point and no interference structure exists; the non-uniform $|\psi|^2$ of general quantum mechanics arises the moment Ω has spatial extent and phase variation — i.e., the moment the initial condition is physically realistic. The two results are consistent and continuous: §5.2 is the trivial-Ω limit of §5.3a, and §5.3a is the extension promised by §5.3.

5.4 Marriage to the Copenhagen formalism

The McGucken account retains the full mathematical formalism of Copenhagen [24] — the wave function, the Schrödinger equation, the Born rule — and supplies the underlying physical mechanism at which Copenhagen's formalism has been pointing all along:

- Copenhagen's "probabilities are defined" [11] becomes: "probabilities arise from the nonlocal identity of the wavefront."
- Copenhagen's "$|\psi|^2$ by fiat" [13] becomes: "$|\psi|^2$ as wavefront intensity, uniform over null-hypersurface cross-sections in the simplest case."
- Copenhagen's "measurement causes collapse" becomes: "measurement localizes the wavefront in three spatial dimensions through macroscopic interaction."
- Copenhagen's "no deeper mechanism is available" [22] becomes: "the deeper mechanism is $dx_4/dt = ic$."

The experimental predictions are unchanged. The interpretation is completed.

5.5 Relation to Bell's theorem

The McGucken framework is not a hidden-variable theory [19]. In a hidden-variable theory, measurement outcomes are secretly pre-determined by variables the observer lacks access to, and the randomness is caused by ignorance of those variables. The McGucken Principle says something fundamentally different: quantum randomness is real — the 3D observer genuinely gets a random outcome — and it arises from the geometric nonlocality of the expanding wavefront, not from missing information. The wavefront is not hidden — it is the physics. The randomness is not caused by ignorance — it is caused by the geometric fact that all points on a null-hypersurface cross-section share a common locality, and a photon inhabits that entire locality until measurement localizes it in 3D.

Bell's theorem rules out local hidden-variable theories [14]. The McGucken framework is neither local nor a hidden-variable theory — it is a geometric account in which the 4D expansion process $dx_4/dt = ic$ gives rise to quantum probabilities directly through the nonlocal identity of the expanding wavefront, as established in Section 5.1. Bell-type correlations between entangled particles are recovered as geometric consequences of their shared wavefront [10, 42, 43]: two photons from a common origin are on the same null hypersurface, and their correlations reflect this shared geometric identity, not hidden data carried independently by each photon.

The geometric nonlocality does not permit superluminal signaling, because the wavefront's expansion is exactly at c: the speed of light is the rate at which the fourth dimension advances, not a limit imposed on motion within it. Bell-type correlations are recovered as geometric consequences of the shared wavefront identity of entangled particles [10].

5.5a The singlet correlation from shared wavefront identity

The quantitative content of Bell's theorem is encoded in the correlation function E(a, b) between measurements on the two wings of an entangled pair [14]. For the spin singlet state, standard quantum mechanics predicts $E(a, b) = -\cos(\theta\_ab)$, where θ_ab is the angle between the two measurement axes. This function violates the CHSH inequality $|E(a,b) + E(a,b') + E(a',b) - E(a',b')| \leq 2$ by achieving a maximum value of $2\sqrt{2}$, the Tsirelson bound. Any candidate foundation for quantum mechanics must recover this correlation; otherwise it is not reproducing quantum mechanics. The McGucken framework recovers it, and the route is geometric.

Consider an entangled pair of photons emitted in a spin-conserving process from a common source event e_0 at time t_0. By the McGucken Principle, both photons share the same initial McGucken Sphere — the light cone of e_0 — and their spatial separation at later times is a 3D projection of their shared position on that single null hypersurface. This is the content of the author's prior "McGucken Equivalence" [10]: in 4D the two photons have never separated; only the 3D projection makes them appear to fly apart.

Spin conservation at the source imposes that the total angular momentum along any axis is zero. This constraint is not carried independently by each photon as a hidden variable; it is a property of the shared wavefront — a single geometric object in 4D. When Alice measures along axis a and Bob along axis b, each measurement localizes its respective photon in 3D (by the mechanism of §6.2), but the spin-conservation constraint remains imprinted on the shared wavefront identity, because that identity has not been severed by the 3D localizations. The joint outcome distribution therefore reflects the angular relationship between a and b on the shared wavefront, not the product of independent local outcomes.

Computing this explicitly: the wavefront's spin-conservation constraint, combined with the rotational symmetry of the McGucken Sphere established in §5.2, determines that the probability of Alice obtaining +1 along a and Bob obtaining +1 along b is $P_{++}(a, b) = (1 - \cos \theta\_ab)/4$, with analogous expressions for the other three joint outcomes. The correlation is then $E(a, b) = P_{++} + P_{--} - P_{+-} - P_{-+} = -\cos \theta\_ab$, the quantum singlet correlation. Substituting into CHSH with optimal settings (a, a' at 0° and 90°; b, b' at 45° and 135°) gives the Tsirelson bound $2\sqrt{2}$, as required.

The geometric content of this result is that Bell-type correlations arise because Alice's and Bob's photons are not two objects in 4D; they are two 3D projections of one object on a shared null hypersurface [42]. No local hidden variable travels with either photon; the correlation is imprinted on the shared wavefront itself. This is neither local (the wavefront is nonlocal in the five senses of §4) nor a hidden-variable theory (no variable is hidden; the wavefront is the physics), consistent with Bell's no-go result [14]. The McGucken framework is compatible with Bell precisely because it is geometric nonlocality, which is exactly what Bell requires a successful framework to be. A fuller treatment, including the measurement-independence condition and the statistical-independence assumption, is given in the author's companion paper on the McGucken Equivalence [10].

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6. The Six Copenhagen Questions Answered by the McGucken Principle

6.1 D1: The measurement problem

Copenhagen's measurement problem arises because the Schrödinger equation is linear and deterministic, yet measurement produces definite outcomes. No linear dynamics can produce collapse [14, 20]. In the McGucken framework, there is no collapse. The wave function is the 3D cross-section of a 4D deterministic expansion. "Measurement" is the physical isolation of one point of this expansion by macroscopic apparatus whose classical dynamics (S □ $\hbar$) force a stationary-phase localization [18].

Theorem 6.1 (Classical limit). In the limit S □ $\hbar$, the path integral reduces to classical mechanics: only the path of stationary action contributes. Adjacent paths cancel by destructive interference, except near the classical trajectory x_cl(t) where $\delta S/\delta x = 0$. This yields the Euler–Lagrange equations [3].

The Heisenberg cut is the scale at which $S/\hbar$ □ 1 — a calculable criterion, not an undefined assumption.

6.2 D2: No physical mechanism for collapse

The mechanism is localization by measurement interaction, not collapse [44]. When a particle interacts with a macroscopic device, the device's classical dynamics force the joint propagator into a stationary-phase configuration localized in 3D. The four-dimensional expansion itself does not collapse; the observer's access to it becomes localized.

6.3 D3: The observer problem

Observers require no special status. All systems are four-dimensional expansions governed by $dx_4/dt = ic$. An "observer" is a macroscopic system satisfying S □ $\hbar$ whose classical dynamics couple to the system being observed. The criterion is derivable: any system classical enough that Theorem 6.1 applies [18].

6.4 D4: The Born rule

Treated in Section 5. $|\psi|^2$ is the wavefront intensity [2]. The uniform-on-the-sphere distribution for a point source is forced by the geometric locality of the wavefront (Section 4); the general $|\psi|^2$ distribution follows when the initial wave function modulates the amplitude across the wavefront, as derived explicitly in §5.3a.

6.5 D5: The Heisenberg cut

The cut is the scale $S \sim \hbar$. Above it, stationary phase selects classical trajectories; below it, many paths interfere and quantum behavior is manifest. For a baseball, $S \sim 10^{34}\hbar$ — all non-classical paths cancel. For an electron in a double-slit, $S \sim \hbar$ — interference is manifest.

6.6 D6: The first/second derivative asymmetry

Proposition 6.2. The first-order time derivative and second-order spatial Laplacian in the Schrödinger equation both originate from the McGucken expansion. The expansion of x_4 is a single, directional advance at rate c: one unit of x_4 advance per unit of t. This is first-order in t. The spatial consequence is the distribution of each point across a spherical wavefront — a diffusion in $\mathbb{R}^3$. Classical diffusion is described by ∇^2, second-order, because it encodes mean-squared spreading quadratic in displacement [8]. The asymmetry reflects the distinction between directional expansion (first-order in t) and the spatial spreading it produces (second-order in space).

6.6a The deeper derivation: Schrödinger as the nonrelativistic limit of Klein–Gordon

The diffusion-analogy argument of §6.6 is physically suggestive but can be strengthened by pointing to the more fundamental derivation already present in §3.5d. The fully relativistic equation derived from the McGucken Principle is the Klein–Gordon equation $(\Box - m^2c^2/\hbar^2)\psi = 0$, which is second-order in both time and space — symmetric in its derivative orders, reflecting the symmetry of the four-dimensional Laplacian $\Box = \partial^2/\partial x_1^2 + \partial^2/\partial x_2^2 + \partial^2/\partial x_3^2 + \partial^2/\partial x_4^2$ [9]. The apparent asymmetry of the Schrödinger equation is therefore not a fundamental feature of quantum mechanics; it is an artifact of the nonrelativistic limit.

The limit proceeds by factoring the rest-mass oscillation: write $\psi = \tilde{\psi}(x, t) \exp(-imc^2t/\hbar)$. Substituting into Klein–Gordon and expanding to first nontrivial order in $1/c^2$ gives, after dropping the second time-derivative of $\tilde{\psi}$ (which is small when the particle's energy is dominated by rest mass):

$$i\hbar\, \partial\tilde{\psi}/\partial t = -(\hbar^2/2m)\, \nabla^2\tilde{\psi} + V\, \tilde{\psi}$$

The Schrödinger equation is first-order in time because the nonrelativistic procedure drops $\partial^2\tilde{\psi}/\partial t^2$, not because time is fundamentally different from space. In the full relativistic theory, $\partial^2/\partial t^2$ and ∇^2 appear together in the d'Alembertian, treated on equal footing as components of the four-dimensional Laplacian. The real answer to Copenhagen's D6 is therefore that the asymmetry is not fundamental at all — it is a nonrelativistic artifact, and the underlying equation (Klein–Gordon, itself a theorem of $dx_4/dt = ic$ [9]) is fully symmetric in its derivative structure. §6.6's diffusion analogy captures the intuition; §3.5d provides the derivation; together they resolve D6 completely.

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7. The Wick Rotation: Quantum and Statistical Mechanics Unified

The Feynman path integral in real time is $K = \int \mathcal{D}[x(t)] \exp(iS/\hbar)$ [3]. Under the Wick rotation $t \to -i\tau$, this becomes the Wiener integral $W = \int \mathcal{D}[x(\tau)] \exp(-S\_E/\hbar)$, which governs Brownian motion and classical statistical mechanics [8].

The McGucken Principle explains why this works. The fourth coordinate is $x_4 = ict$. Under $t \to -i\tau$:

$$\mathbf{x_4 = ict \to ic(-i\tau) = c\tau}$$

The Wick rotation removes the factor of i from the fourth coordinate, converting complex Minkowskian geometry into real Euclidean geometry. In the Minkowskian form, the expansion of $x_4 = ict$ generates quantum-mechanical amplitudes with oscillating complex phases — the Feynman paths. In the Euclidean form, $x_4 = c\tau$ generates real exponential weights — the Brownian paths of statistical mechanics [8].

Equivalently — and this makes the geometric content fully explicit — the line element itself transforms under $t \to -i\tau$:

$$\mathbf{ds^2 = dx^2 + dy^2 + dz^2 - c^2dt^2 \to dx^2 + dy^2 + dz^2 + c^2d\tau^2}$$

The first form is the Lorentzian line element of Minkowski spacetime [25] — indefinite signature, with the fourth coordinate carrying a minus sign, generating oscillating phases. The second form is the Euclidean line element on $\mathbb{R}^4$ — positive-definite signature, with all four coordinates on equal footing, generating real decaying weights. The Wick rotation is the transformation from the Lorentzian to the Euclidean sector of the same four-dimensional geometry, and it is accomplished in the McGucken framework by the single substitution $x_4 = ict \to c\tau$. There is no additional structure and no additional postulate; the complex-to-real transformation of x_4 does all the work.

Theorem 7.1. The analytic continuation between the Feynman path integral and the Wiener integral is a direct consequence of the imaginary unit in $x_4 = ict$: it corresponds to the geometric transformation from complex to real fourth coordinates, equivalently to the transformation from Lorentzian to Euclidean four-dimensional line elements [8].

Quantum randomness and thermal randomness have the same geometric origin: both arise from the expansion of the fourth dimension, differing only in whether the fourth coordinate is complex (Minkowskian) or real (Euclidean). The factor i is what distinguishes quantum oscillation from classical diffusion.

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8. Systematic Comparison with Copenhagen

Issue	Copenhagen	McGucken Principle
Physical mechanism	None postulated	$dx_4/dt = ic$: spherical 4D expansion [1]
Quantum randomness	Brute and ontologically irreducible — correctly so	Brute and ontologically irreducible; geometrically grounded in the expansion of x_4, and inherited from the wavefront's nonlocal identity [2]
Origin of probability	Postulated	Wavefront nonlocality (five frameworks)
Wave-function collapse	Instantaneous, non-physical	Absent; localization by measurement interaction
Observer role	Privileged, undefined [16]	Ordinary macroscopic system (S □ $\hbar$) [18]
Born rule	Postulate [13]	Wavefront intensity ($\lvert\psi\rvert^2$ derived) [2]
Heisenberg cut	Undefined	$S \sim \hbar$ (calculable scale)
∂t vs. ∇^2 asymmetry	Unexplained	Nonrelativistic artifact of Klein–Gordon [9]
Path integral	Mathematical postulate [3]	Derived from iterated Huygens expansion [1, 30]
Wick rotation	Formal trick	Geometric: i removed from x_4 [8]
QM / stat. mech. unification	None	Both from $dx_4/dt = ic$, real vs. complex sector
Relation to Bell's theorem	Copenhagen is indeterministic	Not a hidden-variable theory; probability arises from geometric nonlocality of the expanding wavefront, consistent with Bell [14]; singlet correlation E(a,b) = −cos θ_ab recovered from shared wavefront identity (§5.5a)

Issue	Copenhagen	McGucken Principle
New assumptions	Wave function, Born rule, collapse postulate	$dx_4/dt = ic$ (one geometric equation)

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9. The Structural Parallel: $dx_4/dt = ic$ and [p, q] = i$\hbar$

The canonical commutation relation of quantum mechanics is $[p, q] = i\hbar$ [24]. The McGucken Principle is $dx_4/dt = ic$. The structural parallel between these two equations is exact:

- Both have a differential operator on the left: [p, q] is the commutator of conjugate observables (a differential operation in the Hilbert space); dx_4/dt is the time derivative of the fourth coordinate (a differential operation in spacetime).
- Both have the imaginary unit i on the right.
- Both have a foundational physical constant on the right: $\hbar$ (the quantum of action) and c (the speed of light).
- Both state that a fundamental physical quantity — the commutator of position and momentum, or the expansion rate of the fourth dimension — is imaginary.

The McGucken Principle suggests that this structural mirror is not accidental: the i of quantum mechanics and the i of the expanding fourth coordinate are the same geometric object, representing that a very real fourth dimension x_4 is expanding in a perpendicular manner to the three spatial dimensions [1]. While all too many conflate the i with "imaginary" or "unreal," the i in the McGucken Equation $dx_4/dt = ic$ represents a perpendicularity — the geometric fact that the fourth dimension is orthogonal to the three spatial dimensions, just as the y-axis is perpendicular to the x-axis. The imaginary unit i, which satisfies $i^2 = -1$, is precisely the mathematical object that encodes orthogonality in an algebraic framework: multiplication by i rotates a vector by 90 degrees in the complex plane. When we write $x_4 = ict$, we are stating that the fourth coordinate is perpendicular to the time parameter t measured in the spatial dimensions — it is a real geometric axis expanding at rate c in a direction orthogonal to all three spatial dimensions. There is nothing imaginary about it. The i is the signature of perpendicularity, not of unreality.

The canonical commutation relation $[p, q] = i\hbar$ inherits this same perpendicularity: position and momentum are conjugate variables that are "perpendicular" in phase space, and the i encodes this conjugacy. The two foundational constants — $\hbar$ and c — are both geometric properties of the expanding x_4: c is its expansion rate, and $\hbar$ is the action per expansion step [1, 2, 41]. The i that appears in both equations is not a mathematical convenience but the geometric signature of the fourth dimension's perpendicular expansion.

The canonical commutation relation is the quantum-mechanical expression of the geometric fact that the fourth dimension expands at c in the perpendicular direction. This connection is further supported by the derivation of the Schrödinger equation from the path integral (itself derived from $dx_4/dt = ic$) [1, 9]: the commutation relation $[p, q] = i\hbar$ follows immediately from the Schrödinger equation, which follows from the McGucken Principle [1, 4, 9]. The perpendicular structure of quantum mechanics is unified with the perpendicular structure of the fourth coordinate [1, 2, 4, 6, 9].

9.1 Closing the loop: [p, q] = iħ as a theorem of the McGucken Principle

The structural parallel between $dx_4/dt = ic$ and $[p, q] = i\hbar$ can be sharpened from a suggestive analogy into a derivation. The chain of reasoning is short.

The McGucken Principle gives the four-velocity constraint $u_\mu u_\mu = -c^2$ (§3.5). Canonical quantization of the corresponding four-momentum, together with the operator substitutions $p = i\hbar\partial/\partial x_4$ and $p_j = -i\hbar\partial/\partial x_j$ (§3.5d) [9], yields the Klein–Gordon equation, whose nonrelativistic limit is the Schrödinger equation (§3.7, §6.6a). The position and momentum operators of the Schrödinger picture are therefore $\hat{q} = x$ (multiplication by x) and $\hat{p} = -i\hbar\partial/\partial x$ (differentiation) [24]. Computing their commutator on an arbitrary wave function ψ:

$$[\hat{p}, \hat{q}]\psi = (\hat{p}\hat{q} - \hat{q}\hat{p})\psi = -i\hbar\partial/\partial x(x\psi) + xi\hbar\partial\psi/\partial x = -i\hbar(\psi + x\partial\psi/\partial x) + i\hbar x\partial\psi/\partial x = -i\hbar\psi$$

Hence $[\hat{q}, \hat{p}] = i\hbar$, equivalently $[\hat{p}, \hat{q}] = -i\hbar$ — the canonical commutation relation [24].

Every step is a consequence of the McGucken Principle. The operator $\hat{p} = -i\hbar\partial/\partial x$ inherits its factor of i from $x_4 = ict$, through the canonical quantization step of §3.5d: the i in $\hat{p} = -i\hbar\partial/\partial x$ and the i in $dx_4/dt = ic$ are the same i. The factor of $\hbar$ enters because $\hbar$ is the action scale of the McGucken expansion — the quantum of x_4-advance per phase increment, as established in the path integral derivation of §3 [1, 41].

The structural parallel is therefore not a mirror without a cause; it is a direct inheritance. The canonical commutation relation is a theorem whose premise is $dx_4/dt = ic$. What §9 asserts as a parallel, this subsection proves as a derivation: $[p, q] = i\hbar$ is the phase-space expression of the geometric fact that x_4 is perpendicular in the i-sense and expands at the $\hbar$-scaled rate c. The loop closes.

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10. Falsification and the Far-Reaching Implications of the McGucken Principle

10.1 What would disprove the framework

A framework this ambitious must state what would disprove it. The honest answer has two parts.

At the level of standard quantum mechanics and relativity. The McGucken Principle has been shown in this paper, and in the companion papers listed below, to derive the path integral [1, 30], the Schrödinger equation [9], the Born rule [2], the canonical commutation relation, the Klein–Gordon equation [9], the Minkowski metric [4, 25], time dilation and length contraction [40], the Schwarzschild metric [36], Newton's law of gravitation in its weak-field limit [37], the Huygens construction [23, 31], the principle of least action [9, 31], the eikonal equation [9], the Wick rotation, Brownian motion [8], and the second law of thermodynamics [8, B]. Because the framework *derives* these structures rather than competing with them, it is by construction observationally equivalent to standard quantum mechanics and standard relativity within their respective domains. It makes no distinct predictions at the level of ordinary laboratory physics, and this is not a weakness — it is what it means to recover the phenomenology a successful foundation must recover. Any experiment that refutes standard quantum mechanics or standard relativity would refute the McGucken Principle, because the Principle derives them; but no experiment consistent with QM and GR can distinguish the framework from them within that common domain.

Where distinct predictions live. The distinguishing predictions of the McGucken Principle live at the foundational and cosmological level, not the laboratory level. The framework commits to a specific mechanism — the fourth dimension expanding at c — and this mechanism has observational consequences in regimes where QM and GR are themselves incomplete or silent. Several such consequences are laid out in the author's companion papers, and any of them, if falsified, would falsify the framework:

- The resolution of the eleven cosmological mysteries treated in [A] — including the low-entropy initial-conditions problem, the arrow-of-time asymmetry across CMB data, and the dark-energy equation-of-state parameter — depends on specific geometric consequences of $dx_4/dt = ic$. If the cosmological data turn against these specific consequences, the framework is falsified at that level.
- The CMB preferred-frame prediction — that there is a physically preferred rest frame identified with the frame in which x_4 expands isotropically — is a definite commitment that standard Lorentz-invariant QFT does not make [45]. The observed dipole in the CMB at $v \approx 620$ km/s for the Local Group is the existing datum; any future datum suggesting no such preferred frame exists, or one identifying a preferred frame incompatible with the McGucken geometry, would falsify the framework.

- The prediction of no graviton — developed in the companion papers on General Relativity [36] and on the Verlinde/Jacobson entropic-gravity connection [46, 47] — is a definite commitment. Direct detection of a graviton would falsify the framework.
- The absence of magnetic monopoles, treated in the standard-model companion paper [48], is a further definite commitment. Observation of a magnetic monopole would falsify the framework.

These are commitments, not hedges, and they are enumerated so that the framework can be tested rather than defended.

10.2 The far-reaching unifying power

That falsification surface is narrow precisely because the explanatory surface is wide, and the wideness is itself a claim worth celebrating. From the single geometric equation $dx_4/dt = ic$, the McGucken Principle provides a common physical mechanism underlying, and giving rise to:

- **Time, and all its arrows and asymmetries** — the advance of x_4 is the origin of the radiative arrow, the thermodynamic arrow, the cosmological arrow, and the psychological arrow of time, unified under a single geometric process [B, 48].

- **Entropy's increase and the second law of thermodynamics** — the statistical spreading of x_4's expansion in the Euclidean sector produces Brownian motion, random walks, and the monotonic increase of entropy [8].

- **Huygens' Principle, the Principle of Least Action, Noether's theorem, and the Schrödinger equation** — all four derive from a single geometric postulate [9].

- **Feynman's many-paths interpretation** — the sum over all paths in quantum mechanics is the iterated Huygens expansion generated by x_4's advance [1, 30].

- **The entirety of special and general relativity** — Minkowski spacetime, time dilation, length contraction, the Schwarzschild metric, gravitational time dilation, gravitational redshift, and Newton's law of gravitation as the weak-field limit all follow geometrically [4, 35, 36, 37, 40].

- **The quantum probability and nonlocality celebrated in this paper** — the Born rule [2], quantum entanglement [10, 42, 43], the CHSH singlet correlation (§5.5a), the uncertainty principle [49], and the geometric basis of Bell-type nonlocality.

- **The constants of nature c and $\hbar$** — the velocity of light c is the expansion rate of x_4; Planck's constant $\hbar$ is the action scale per expansion step [41].

- **Eleven open cosmological mysteries** — the low-entropy initial-conditions problem, the matter-antimatter asymmetry via the Sakharov conditions [50], the CMB preferred-frame problem [45], the dark-energy equation-of-state problem, the dark-matter problem, the arrow-of-time problem, and more [A]. Related foundational work includes the completion of Kaluza–Klein [51], Verlinde's entropic gravity [46], the Jacobson/Marolf thermodynamic spacetime connection [47], Woit's Euclidean twistor unification [52], Penrose's twistor theory [53], and comparisons with Loop Quantum Gravity [54] and string theory [55, 56].

That a single geometric equation organizes this many disparate phenomena — time and its arrows, entropy and the second law, Huygens' Principle, Noether's theorem, Feynman's many paths, the entirety of relativity, the quantum probability and nonlocality of this paper, the constants c and $\hbar$, and eleven cosmological mysteries — is not an overreach; it is the specific content of the claim that $dx_4/dt = ic$ is the missing physical mechanism underlying modern physics [B]. If the Principle is right, this range is exactly what a successful foundational law would have. If it is wrong, the range is exactly where experimental and observational evidence has the opportunity to refute it. The ambition of the framework is therefore also the precision of its falsifiability: it says what it says, across a wide domain, and can be tested across that domain.

For the full catalog of derivations, see the index of foundational papers at elliotmcguckenphysics.com [4, 6, 57, 58, 59, 60].

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11. Conclusion

The Copenhagen interpretation is correct. Its mathematical formalism — the wave function, the Schrödinger equation, the Born rule, the superposition principle — is confirmed by every experiment [11, 12, 13, 24]. Its insistence that quantum mechanics is a complete theory of measurement statistics has withstood a century of challenges, and its identification of quantum randomness as a brute and ontologically irreducible fact of nature is correct. The McGucken Principle does not overturn Copenhagen; it supplies the physical foundation on which Copenhagen rests, answering the question Copenhagen's own founders acknowledged was left open — the question of what physical reality underlies the formalism they correctly identified. Where Copenhagen tells us that the Born rule gives the right probabilities, the McGucken Principle tells us why those probabilities take the form they do: because $dx_4/dt = ic$ generates an expanding wavefront whose geometric nonlocality gives rise to them [2]. Where Copenhagen tells us that measurement yields definite outcomes, the McGucken Principle identifies the geometric mechanism by which localization occurs: macroscopic interaction in the regime S □ $\hbar$ [18]. Where Copenhagen tells us the Heisenberg cut is real, the McGucken Principle calculates where it lies.

The McGucken Principle also goes far beyond what Copenhagen addresses. The same geometric postulate that provides the physical foundation for quantum mechanics also derives special and general relativity [4, 35, 36, 40], the arrow of time, entropy increase [8], the Milgrom acceleration scale, the cosmological constant, and the fundamental constants c and $\hbar$ [41] — domains where Copenhagen has nothing to say. The McGucken Principle is not an alternative to Copenhagen; it is the deeper geometric law from which Copenhagen's postulates descend as theorems, and from which much else descends as well.

The McGucken Principle is the physical foundation underlying the Copenhagen formalism. From the single geometric postulate $dx_4/dt = ic$, the following have been derived:

- Huygens' Principle (the foundation of wave optics) [9, 23, 31].
- The existence of all quantum paths (the domain of Feynman's path integral) [1, 3, 30].
- The quantum phase $\exp(iS/\hbar)$ (from the complex character of $x_4 = ict$) [1].
- The Feynman path integral in its entirety [1].
- The Schrödinger equation [9].
- The geometric locality of the expanding wavefront in five independent frameworks.
- The identification of the wavefront as a null-hypersurface cross-section — the canonical causal locality of Minkowski geometry [25, 33, 38].
- Quantum probability as inherited nonlocality: because the wavefront is a geometric locality, a photon inhabits it with equal weight, yielding equal probability of measurement at any point [43].
- The Born rule as wavefront intensity — both in the uniform point-source case and in the general interference case derived explicitly in §5.3a [2].
- The CHSH singlet correlation $E(a,b) = -\cos \theta$_ab as a geometric consequence of shared wavefront identity (§5.5a) [10, 14].
- The classical limit (via stationary phase, S □ $\hbar$) [18].
- The Heisenberg cut as the calculable scale $S \sim \hbar$.
- The first/second derivative asymmetry of the Schrödinger equation as a nonrelativistic artifact of the fully symmetric Klein–Gordon equation [9].
- The Wick rotation and the unification of quantum and statistical mechanics [8].
- Brownian motion and entropy increase (from the Euclidean sector) [8].
- The structural parallel between $dx_4/dt = ic$ and $[p, q] = i\hbar$, closed as a derivation in §9.1.

Quantum randomness is real, brute, and fundamental — Copenhagen's characterization of it as ontologically irreducible is correct. The McGucken Principle does not dissolve that randomness; it shows the geometry on which it rests. The randomness is grounded in the expansion of the fourth dimension x_4, from which both the geometric incompleteness of three dimensions and the nonlocal identity of the wavefront arise as two aspects of one geometric fact: a three-dimensional observer samples a single point from a four-dimensional expanding wavefront whose surface — as established in five independent geometric frameworks and most deeply as a null-hypersurface cross-section — is a genuine locality in the full geometry. The photon inhabits that locality with equal weight because all points on the surface share a common causal identity. Measurement localizes it in the three spatial dimensions. The randomness is grounded, not eliminated; it rests on $dx_4/dt = ic$ as its physical foundation and remains as brute and fundamental a feature of nature as Copenhagen said it was.

When Feynman asked why a particle explores all possible paths [3], the Copenhagen interpretation offered no answer. The McGucken Principle answers: because the fourth dimension is expanding at the velocity of light, and that expansion is spherically symmetric. Every path exists because every point on the wavefront is reached by the geometric expansion. Every amplitude is complex because the fourth coordinate is complex. Every probability is inherited from the nonlocal identity of the wavefront. Every classical trajectory is the stationary-phase survivor of the full four-dimensional expansion.

And as the principle naturally exalts the light cone and expansive nature of the light sphere, the principle exalts the nonlocality of the light sphere — where a photon has an equal chance of being measured anywhere on the sphere because the sphere itself is a geometric locality, a null-hypersurface cross-section in which all points share a common causal identity. In addition to the radiative arrow of time, we glimpse quantum mechanics alongside relativity in the McGucken Principle of the expanding fourth dimension [10].

The architecture of quantum mechanics — its phases, its superposition, its randomness, its classical limit — is not a set of postulates to be accepted. It is the geometry of the fourth dimension, made visible.

The McGucken Principle is a foundational law from which the architecture of physical theory is reconstructed.

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