

Can the Brain Function as a Quantum Information Transducer?

An Eight-Principle Synthesis from Biological Precedents to Microtubule Coherence

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Abstract

Anesthesia has been used since 1846, yet the precise molecular mechanism by which it extinguishes consciousness remains unsolved after 180 years. The Meyer-Overton correlation (1899) suggests that chemically diverse anesthetics act on a single common target, but the identity of that target has not been established. This paper does not propose new physics. Instead, it sequentially connects eight principles that have developed independently and received varying levels of experimental and theoretical support — (1) room-temperature quantum coherence in photosynthesis, (2) the avian quantum compass, (3) experimental confirmation of macroscopic quantum effects (2025 Nobel Prize in Physics), (4) the QED cavity structure of microtubules, (5) Fröhlich condensation for room-temperature coherence maintenance, (6) evidence for microtubules as an anesthetic target, (7) reported non-classical signals correlated with consciousness state, and (8) Integrated Information Theory (IIT 4.0) — to construct a single integrative pathway.

This integrative pathway motivates two interpretations of brain function: (a) the brain as a quantum production device that internally generates and processes quantum information, and (b) the brain as a quantum transduction device that receives and converts quantum information from external sources. Current data cannot distinguish (a) from (b). The core contribution of this paper is to explicitly separate these two interpretations and propose a first discriminating test (Prediction 7: electromagnetic shielding experiment) to distinguish EM-based transduction from internal production.

As a secondary exploratory extension, the structural coherence between William James's (1898) transmission theory and modern quantum experiments is briefly examined. Seven testable predictions (five based on existing principles + two model-specific) establish falsifiability.

Keywords: quantum biology, microtubules, quantum coherence, anesthesia, consciousness, Fröhlich condensation, information transduction, integrated information theory, binding problem

1. Introduction

In 1846, William Morton performed the first public demonstration of ether anesthesia. In the 180 years since, anesthesia has become a foundation of modern medicine. Yet remarkably, the answer to 'exactly how does anesthesia turn off consciousness?' remains unknown [1]. This is one of the oldest unsolved problems in modern medicine.

Meyer (1899) and Overton (1901) discovered that anesthetic potency correlates with olive oil solubility [2]. The fact that chemically unrelated anesthetics additively contribute to the same effect suggests a common physicochemical substrate or biophysical principle. Mainstream neuroscience has explained anesthetic action through ion channels, receptors, and synaptic proteins [3]. However, a residual explanatory gap remains in this model: 'If anesthetics bind

indiscriminately to diverse proteins, why does only consciousness selectively shut down?

Between 2022 and 2026, three independent lines of research converged in the same direction: (a) room-temperature quantum effects in microtubules were experimentally observed (Babcock 2024) and reviewed in an integrative synthesis (Wiest 2025) [4,5]. (b) Quantum entanglement signals correlated with consciousness were detected by MRI in living human brains (Kerskens and Pérez 2022, 2023) [6,6b]. (c) The premise that 'room-temperature quantum effects are impossible' was experimentally refuted in photosynthesis, migratory birds, and macroscopic superconducting systems [7,8,9].

An important gap remains in the literature. Although these eight principles have each developed independently, no integrative pathway sequentially connecting them to reinterpret brain function has been proposed. In particular, to our knowledge, no prior study has explicitly separated 'quantum production' and 'quantum transduction' models, compared them, and proposed a first discriminating test to experimentally distinguish the two.

This paper is an integrative synthesis that sequentially traces the logical consequences of existing principles. The contributions are eightfold: (1) a sequential integration pathway of eight principles, (2) explicit separation of quantum production and quantum transduction models, (3) the proposal that the brain may function as a quantum information transducer, (4) design of a discriminating experiment for production/transduction distinction (Prediction 7), (5) a structural candidate answer to the binding problem from the transduction model, (6) five existing-principle-based predictions + two model-specific predictions, (7) exploratory coherence check with transmission theory, and (8) a scaling relation (Eq. 6), simulation (Figure 2), and an integrated anesthesia scenario (§3.8, Figure 3) linking coherence time to integrated information.

Methodological justification: This paper does not conduct new experiments. Instead, it adopts the methodology of integrative synthesis, sequentially tracing logical consequences of independently developed principles. The value of integrative synthesis lies in revealing connections and consequences that the sum of individual principles does not show. The limitation of this methodology is clear: the validity of connections is constrained by the strength of the weakest principle, and logical consequences without experimental confirmation do not exceed the status of hypotheses.

Terminological definition: In this paper, 'quantum information processing' encompasses storage, transmission, and conversion of information based on quantum coherence and quantum entanglement, and does not imply universal quantum computation. 'Information' is used in four distinct senses, distinguished by subscript throughout: H_{Shannon} (Shannon 1948, substrate-independent entropy), I_{physical} (Landauer 1961, thermodynamically real information), Φ_{IIT} (Tononi 2023, integrated information of conscious systems), and Q_{info} (quantum information carried by coherent/entangled states). These four layers are related but not identical; transitions between them are explicitly marked in the text.

2. Prior Work

This section summarizes prior work on the eight principles. Detailed argumentation for each principle is developed in Section 3.

2.1 Biological Quantum Precedents: Photosynthesis and Migratory Birds

In 2007, the Engel research team first observed quantum coherence in photosynthetic proteins [7]. Room-temperature (300 K) quantum coherence was subsequently confirmed, and in 2025 the Lorenzoni team reconfirmed the existence of room-temperature picosecond quantum coherence through non-perturbative simulation [10]. Migratory birds sense Earth's magnetic

field through quantum-entangled radical pairs in retinal cryptochrome proteins [11]. Photosynthesis (3.8 billion years) and migratory birds (tens of millions of years) — these two independent biological precedents serve as counterexamples to the premise that 'room-temperature quantum effects are impossible.'

2.2 Experimental Confirmation of Macroscopic Quantum Effects

The 2025 Nobel Prize in Physics was awarded to Clarke, Devoret, and Martinis for experimentally demonstrating macroscopic quantum mechanical tunneling and energy quantization in superconducting electrical circuits [9]. In 2026, a research team at the University of Innsbruck demonstrated in a many-body dynamical localization (MBDL) experiment that quantum coherence can resist heating itself [12].

2.3 Quantum Properties of Microtubules

Microtubules are cylindrical protein polymers with a diameter of 25 nm, composed of 13 tubulin dimer protofilaments. Mavromatos et al. (2025) modeled the microtubule interior as a high-quality QED cavity and showed that decoherence time can extend to 10^{-6} seconds [13]. Babcock et al. (2024) directly observed room-temperature quantum superradiance in microtubules, confirming that superradiance strengthens as temperature increases [5]. Echternach (2025) synthesized convergent evidence from five independent research teams to argue for the legitimacy of direct measurement [14]. Beshkar (2025) demonstrated in QBIT theory that microtubules can generate spontaneous quantum coherence as spintronic oscillators [15].

2.4 Fröhlich Condensation and Criticisms

Fröhlich (1968) mathematically proved that continuously supplying energy to an electric dipole system can produce stable coherent condensation even at high temperatures [16]. This model and quantum effects in the brain in general have faced two major criticisms. First, Tegmark (2000) denied quantum effects in the brain, but Hagan et al. (2002) immediately rebutted [17,18]. Second, Reimers et al. (2009, PNAS) claimed Fröhlich condensation is impossible at biological temperatures [40], but Salari et al. (2011) pointed out errors in the modeling assumptions [41]. Detailed rebuttals to both criticisms are developed in §3.2. Zhang et al. (2019, PRL) theoretically confirmed quantum fluctuations of Fröhlich condensation under non-equilibrium driven conditions [42]. Subsequently, Babcock's (2024) direct observation of room-temperature superradiance [5] provided experimental data to this debate.

2.5 Anesthesia and Microtubules

Khan et al. (2024, Wiest lab) reported that rats administered microtubule-stabilizing drugs took significantly longer to lose consciousness under anesthesia (Cohen's $d = 1.9$) [19]. Craddock et al. (2017) reported quantum chemistry modeling results showing that anesthetics disrupt quantum electronic resonance in tubulin [20]. Emerson (2013) reported similar results in tadpoles, and Linganna (2015) in human patients [38,39].

2.6 Observation of Quantum Entanglement in the Living Brain

Kerskens and Pérez (2022) scanned 40 subjects with MRI and detected quantum entanglement signals that appeared only when subjects were conscious [6]. When two subjects fell asleep, the signal disappeared and returned upon waking. Kerskens and Pérez (2023) rebutted Warren's alternative classical explanation, reconfirming the validity of the original observation [6b]. In a second experiment (60 subjects, ages 18–29 and 65+), signal instability increased with age and correlated with short-term memory performance (cited in Wiest 2025 review) [4].

Independent replication does not yet exist, and this paper treats this observation strictly as correlation.

2.7 Information Theory of Consciousness and Quantum Cognition

Tononi's (2004, 2023) Integrated Information Theory (IIT) defines consciousness as integrated information (Φ) [21,22]. In the 2025 Nature adversarial collaboration, IIT showed partial empirical support on some tested predictions, though both IIT and the competing theory (GNWT) had core tenets challenged by the results [23]. Meanwhile, Wang et al. (2014) and Pothos & Busmeyer (2022) reported that human decision-making is not explained by classical Bayesian probability but is unified by quantum probability formalism [43,44]. This suggests that quantum information processing has convergent evidence at the behavioral level as well.

2.8 Orch OR and the Distinction of This Paper

Penrose and Hameroff's Orchestrated Objective Reduction (Orch OR) theory claims that consciousness arises in microtubules — a quantum version of the production model [27]. This paper accepts Orch OR's physical substrate (microtubules) but differs in interpretive framework: it explicitly separates the quantum transduction model ('microtubules convert quantum information') as a distinct proposal. The two models are compatible but experimentally distinguishable (see Prediction 7 in Section 6). Wiest (2025) identified solving the binding problem as the strongest theoretical motivation for quantum consciousness models [4].

3. Sequential Integration of Eight Principles

3.1 The 'Room-Temperature Quantum = Impossible' Premise Does Not Hold as a Universal Objection

[Key] The premise that 'quantum effects are impossible in warm environments' does not hold as a universal objection.

Photosynthesis has performed room-temperature quantum energy transfer for 3.8 billion years. Migratory birds use a quantum compass daily at 37°C. The 2025 Nobel Prize in Physics confirmed quantum effects in macroscopic systems. The Innsbruck MBDL experiment (2026) showed that quantum coherence can resist heating itself. These four independent lines of evidence demonstrate that Tegmark's (2000) premise 'too warm for quantum' is not universal. This step is not proof that quantum effects operate in microtubules — it is the removal of the 'impossibility barrier.'

3.2 Structure: Microtubules Possess a Room-Temperature Quantum Protection Structure

[Key] Microtubules possess a structure that protects quantum coherence at room temperature.

Mavromatos (2025) modeled the microtubule interior as a high-quality QED cavity and estimated coherence time at 10^{-6} seconds [13] — ten million times longer than Tegmark's estimate (10^{-13} s). Babcock (2024) directly observed room-temperature quantum superradiance in microtubules [5]. Fröhlich's (1968) condensation model mathematically showed that continuous energy supply maintains high-temperature coherence [16]. Paper 9 [50] derives brain-specific Fröhlich parameters: pump efficiency $\alpha_F = 1.38 \times 10^{-4}$, metabolic pump rate $S = 2.37 \times 10^{24} \text{ s}^{-1}$, and decoherence rate $\gamma = 10^{13} \text{ s}^{-1}$, providing quantitative support for the biological plausibility of Fröhlich condensation in neural tissue. The rebuttal to the Tegmark objection is threefold: (a) the thermal equilibrium assumption equals death (Hagan 2002) [18],

(b) Tegmark assumed a tubulin separation distance of ~24 nm (full dimer diameter); Hagan showed the relevant separation is ~0.5 nm, reducing decoherence by ~2,300× (Hagan 2002), (c) energy pumping maintains coherence (Fröhlich 1968). The brain is not a closed beaker (thermal equilibrium system) but an open engine (non-equilibrium system) — metabolic energy is continuously supplied through eating and breathing. Paper 8 [47] independently derives a Fröhlich protection factor $F \approx 10^7$ from first principles: $\tau = F \cdot \tau_{\text{bare}} = 10^7 \times 10^{-13} \text{ s} = 10^{-6} \text{ s}$, converging with Mavromatos's QED cavity estimate from a completely different derivation pathway. This two-path convergence on the same order of magnitude (10^{-6} s) strengthens the case that the Tegmark decoherence estimate is not merely wrong in degree but wrong in kind — it assumes thermal equilibrium in a system that is fundamentally non-equilibrium.

Eq. 1 (Coherence time): $\tau_{\text{Tegmark}} \approx 10^{-13} \text{ s}$ vs $\tau_{\text{Mavromatos}} \approx 10^{-6} \text{ s}$ ($10^7 \times$ difference)
(Intuition: The microtubule QED cavity structure extends coherence time by ten-million-fold)

Eq. 2 (Fröhlich): $dE/dt > E_{\text{threshold}} \rightarrow \text{non-equilibrium condensation} \rightarrow \text{room-temperature coherence}$
(Intuition: If energy is continuously supplied to the brain, quantum coherence can be maintained even at body temperature)

A dual rebuttal also holds against the Reimers et al. (2009) objection: (a) Salari et al. (2011) — Reimers modeled one-dimensional polymers, not cylindrical microtubules [41]. (b) Babcock (2024) — direct observation of room-temperature microtubule superradiance provided experimental closure to the debate [5].

3.3 Observation: The Anesthetic Target Is Microtubules

[Key] When anesthetics disrupt microtubule structure, consciousness shuts down.

Mainstream anesthesia models have proposed diverse protein targets including GABA_A receptors and ion channels [3]. However, a residual explanatory gap exists in this model regarding the mechanism by which consciousness alone is selectively extinguished despite indiscriminate binding to diverse targets. This raises the possibility that the substrate of consciousness possesses an organizational principle qualitatively distinct from other neural functions. The following experimental evidence suggests that microtubules are a candidate for this 'qualitatively distinct substrate.' These data elevate microtubules as a plausible candidate, not yet an exclusive one.

Khan et al. (2024) showed that rats administered microtubule stabilizers resisted anesthesia longer ($d = 1.9$) [19]. Emerson (2013) reported similar results in tadpoles, and Linganna (2015) in human patients [38,39]. Craddock's (2017) quantum chemistry model supports the interpretation that anesthetics disrupt quantum electronic resonance in tubulin [20].

Eq. 3 (Meyer-Overton): *The minimum alveolar concentration (MAC) is inversely proportional to olive oil–gas partition coefficient ($K_{\text{oil/gas}}$), implying a common hydrophobic target.*

(Intuition: Anesthetic potency is proportional to olive oil solubility — physical interaction, not chemical structure, is key. This correlation implies a common hydrophobic target)

Potential confounders: (a) Khan 2024 is a rodent study requiring human extension, (b) microtubule stabilizers may affect other cellular functions, (c) whether disruption is quantum or classical-structural has not yet been distinguished. However, in quantum error correction theory, 'structural disruption = quantum protection failure' holds [25], and if this principle applies to microtubules, the quantum/classical distinction itself may be a false dichotomy.

3.4 Observation: A Correlation Exists Between Consciousness State and Quantum Entanglement Signals

[Key] Quantum signals appear when conscious and disappear when consciousness is lost.

In Kerskens' (2022) experiment, quantum entanglement signals appeared when subjects were conscious and disappeared when they fell asleep [6]. A second experiment (60 subjects), cited in Wiest (2025) [4], reported correlation with age and short-term memory. Causal direction cannot be determined from current data, and independent replication is needed (Prediction 3). Kerskens attached the conditional 'if entanglement is the only possible explanation,' and alternative classical explanations have not been fully excluded.

According to the principle of methodological triangulation (Denzin 1978), observational reliability increases when independent methods point in the same direction [26]. Sections 3.3 (anesthesia-microtubule, rodent experiments) and 3.4 (consciousness-quantum, human MRI) point in the same direction using independent methodologies: 'microtubule-related and quantum-related observations both covary with consciousness state.' However, whether the microtubule evidence of §3.3 and the quantum signal evidence of §3.4 originate from the same substrate (microtubules) has not yet been confirmed. Taken together, these observations are mutually compatible with the hypothesis that consciousness-related changes covary with quantum-level changes, but confirmation of a common mechanism depends on Prediction 1 (quantitative measurement of microtubule quantum coherence during anesthesia). In this integrative pathway, this step (Principle 7) is the weakest empirical bridge, and independent replication carries the highest priority.

3.5 Framework: If Consciousness Is a Form of Information

[Key] If consciousness is defined as information, it is structurally consistent with quantum information processing.

If the observations of §3.2–3.4 suggest that 'quantum information processing (Q_info) occurs in the brain,' the next question is 'is consciousness a form of information?' According to IIT 4.0, consciousness is integrated information Φ_{IIT} [21,22]. Just as Shannon (1948) defined H_{Shannon} as substrate-independent [24], IIT's Φ_{IIT} also does not require a specific physical substrate. Furthermore, Landauer (1961) proved that I_{physical} is not purely abstract [46]: erasing one bit of information generates $kT \ln 2$ of heat, meaning information is a physical reality. The unitarity principle of quantum mechanics requires that information is physically indestructible, a principle experimentally and theoretically supported in the black hole information paradox (Hawking 2005; Susskind 2008) [48,49]. Paper 4 [35] develops this argument further: if even black holes — the most extreme gravitational objects in the universe — cannot destroy information (as demonstrated by the Page curve, Hayden-Preskill protocol, and ER=EPR wormhole teleportation experiments), then information conservation at the brain level is a far less demanding claim. The unitarity constraint applies a fortiori to biological systems. Paper 8 [47] formalizes these transitions as the closed loop $m \rightleftharpoons E \rightleftharpoons I \rightleftharpoons C$: mass has energy (Einstein), energy carries information (Landauer), information generates consciousness (Ω_0), and consciousness creates information (observation). The step from I_{physical} to Q_{info} is the hypothesis under test: if microtubules maintain quantum coherence (§3.2), then I_{physical} in the brain may be carried as Q_{info} . Therefore, the possibility that Q_{info} processing serves as the physical implementation mechanism of Φ_{IIT} is structurally consistent with the IIT framework. This is consistent, not necessary. Directly applying IIT 4.0's Φ_{IIT} to quantum systems remains an unresolved challenge (Tononi 2023) [22], and this consistency is limited to the in-principle level.

Eq. 4 (Shannon): $H_{Shannon} = -\sum p_i \log_2 p_i$
(Intuition: The definition of information does not depend on physical medium — substrate independence)

Eq. 5 (IIT 4.0): $\Phi_{IIT} = \text{integrated information of the system (excess over minimum partition)}$
(Intuition: Consciousness = irreducible integrated information. Quantum information processing is a possible physical implementation of Φ)

Before proceeding to the synthesis, the evidentiary status of the pathway should be made explicit. What has been shown: (a) room-temperature quantum effects exist in biological systems outside the brain (photosynthesis, avian compass); (b) microtubules possess structures compatible with quantum coherence (QED cavity, superradiance); (c) microtubule stabilization delays anesthetic-induced unconsciousness in rodents; (d) a correlation between consciousness state and quantum entanglement signals has been observed in one lab. What has not yet been shown: (e) that the microtubule evidence of §3.3 and the quantum signal evidence of §3.4 originate from the same substrate; (f) that quantum effects in microtubules are causally necessary for consciousness rather than epiphenomenal; (g) independent replication of the Kerskens observation. The synthesis below should be read with this distinction in mind.

3.6 Synthesis: Reading the Entire Staircase as One

Compressing the eight principles into five steps: (1) Room-temperature quantum effects are biologically possible (§3.1, Principles ①②③). (2) Microtubules possess a protective structure for this (§3.2, Principles ④⑤). (3) When anesthetics disrupt this structure, consciousness shuts down (§3.3, Principle ⑥). (4) A correlation is observed between consciousness and quantum signals (§3.4, Principle ⑦). (5) If consciousness is a form of information, it is consistent with quantum information processing (§3.5, Principle ⑧). The logical consequence of this sequential pathway is: the brain can be interpreted as a device that processes quantum information (Figure 1).

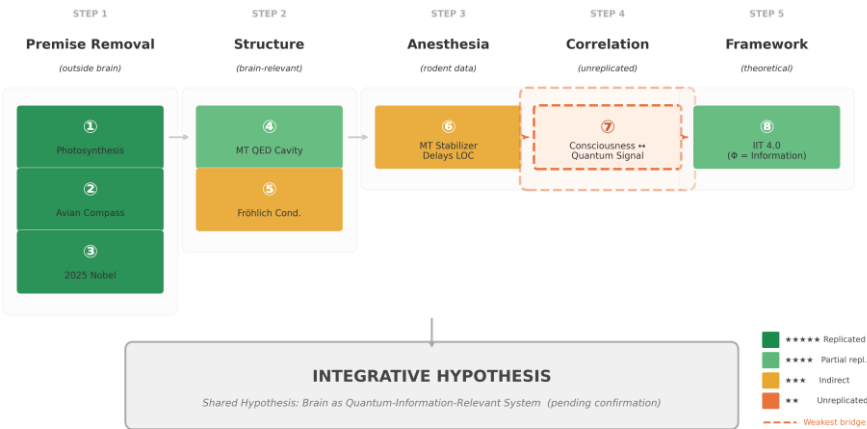


Figure 1. Eight-Principle Staircase Integration Pathway. Each bar represents one principle; color indicates evidence strength (Preliminary to Strong ★). Dashed orange border marks Principle ⑦ as the weakest empirical bridge requiring independent replication. Left brackets indicate corresponding sections and evidence type (§3.1–§3.5). Top bar: integrative hypothesis labeled as pending experimental confirmation. (Conceptual diagram by author)

Table 1. Evidence Strength Rating by Principle

Principle	Replication Status	Brain Relevance	Causal Specificity	Evidence Status
① Photosynthesis	Multiple teams, replicated	Indirect (outside brain)	Premise-removal support (not direct)	Established (standalone)

			brain evidence)	
② Avian compass	Multiple teams, replicated	Indirect (outside brain)	Not brain-specific	Established (standalone)
③ 2025 Nobel (SC)	Definitive (Nobel)	Premise-removal only (not direct brain evidence)	Not brain-specific	Established (standalone)
④ MT QED cavity	Theory + partial exp.	Direct (microtubules)	Moderate	Strong
⑤ Fröhlich cond.	Theory + Zhang 2019	Direct (microtubules)	Moderate	Moderate
⑥ Anesthesia–MT	1 team (Khan 2024)	Direct (rodent brain)	Strong (d = 1.9)	Moderate
⑦ Kerskens MRI	1 team, unreplicated	Direct (human brain)	Correlational only	Preliminary
⑧ IIT 4.0	Framework-level empirical testing (partial support, partial challenge)	Framework (any substrate)	Theoretical	Strong

(Rating criteria: Overall rating reflects standalone evidence strength. Three diagnostic axes — Replication Status, Brain Relevance, and Causal Specificity — are provided separately to allow readers to assess each principle's contribution to the integrative pathway independently. Principles ①–③ rate Strong★ as standalone demonstrations but are indirect for brain application (premise removal only). Principle ⑦ is the weakest empirical bridge: direct brain measurement but single-team and unreplicated.)

Table 2. Logical Status of Each Connection (→)

Step	Connection	Logical Status
3.1 → 3.2	Premise refuted → Structure exists	Premise refuted (necessary condition secured)
3.2 → 3.3	Structure exists → Anesthetic target	Experimental correlation (d = 1.9)
3.3 → 3.4	Anesthetic target → Consciousness–quantum corr.	Cross-method compatibility (common substrate unconfirmed)
3.4 → 3.5	Consciousness–quantum corr. → Information framework	Structural consistency
3.5 → Synthesis	Information framework → Reinterpretation	Logical consequence (integrative synthesis)

3.7 Exploratory Scaling Ansatz: Relationship Between Quantum Coherence and Integrated Information (Novel Proposal, to Our Knowledge)

From the synthesis of §3.6, the consequence 'the brain can be interpreted as a device that processes quantum information' was derived. To provide a heuristic toy model rather than a fully specified quantitative framework, we propose a phenomenological scaling ansatz between microtubule quantum coherence time (τ_{coh}) and effective integrated information (Φ_{eff}). This ansatz bridges Mavromatos's (2025) coherence time model [13] and Tononi's (2023) IIT 4.0 [22], and has not, to our knowledge, been explicitly proposed in the literature to date. It is intended as a qualitative guide for experimental design, not as a mechanistic model. A more rigorous formulation of the consciousness threshold appears in Paper 8 [47] as $C = \Theta(R\tau/I - 1)$, where R is the Landauer processing rate, τ is Fröhlich-protected coherence time, and I is brain information content. Equation hierarchy: Eq. 6 of this paper is a local phenomenological heuristic (this paper's contribution); $C = \Theta(R\tau/I - 1)$ is an analytical result from companion work (Paper 8 [47]). Eq. 6 motivates experimental design; Paper 8's equation provides formal structure. The two are compatible but operate at different levels of rigor. Specifically, τ_{coh} corresponds to Paper 8's τ , and the Heaviside gate Θ serves the same role in both formulations,

but Paper 10 further derives $R\tau/I = 1$ as the unique globally asymptotically stable fixed point — a result this paper's heuristic does not attempt.

Eq. 6 (Proposed): $\Phi_{\text{eff}} = N \cdot \Theta(\tau_{\text{coh}} - \tau_{\text{threshold}}) \cdot (\tau_{\text{coh}} / \tau_{\text{threshold}})^\gamma$

(Intuition: Effective integrated information = participating microtubule count \times step function \times coherence scaling)

Here, N is the number of microtubules participating in quantum coherence, τ_{coh} is the actual coherence time (Mavromatos model), $\tau_{\text{threshold}}$ is the minimum coherence time associated with a putative consciousness threshold, Θ is the Heaviside step function (0 if $\tau < \tau_{\text{threshold}}$), and γ is a scaling exponent (to be determined experimentally). Convention: throughout this paper, $\Theta(0) = 0$ (consciousness requires strictly exceeding the threshold). This relation generates three specific predictions:

(a) Coherence time gap: At body temperature (310 K), a 10^7 -fold gap exists between the Tegmark model's $\tau \approx 10^{-13}$ s and the Mavromatos model's $\tau \approx 10^{-6}$ s (Figure 2a). If the Mavromatos model is correct, $\tau_{\text{coh}} > \tau_{\text{threshold}}$ holds at body temperature, yielding $\Phi_{\text{eff}} > 0$ — consciousness is possible. If the Tegmark model is correct, $\tau_{\text{coh}} \ll \tau_{\text{threshold}}$ so $\Phi_{\text{eff}} = 0$ — no quantum contribution to consciousness.

(b) Discontinuous step pattern by consciousness level: As consciousness level changes (death \rightarrow general anesthesia \rightarrow deep sleep \rightarrow REM sleep \rightarrow awake), τ_{coh} varies, and due to the Heaviside step function Θ , Φ_{eff} shows a discontinuous step pattern rather than continuous decay (Figure 2b). This is the mathematical basis for Prediction 6. Under general anesthesia, $\tau_{\text{coh}} < \tau_{\text{threshold}} \rightarrow \Phi_{\text{eff}} = 0$ (consciousness lost), and when τ_{coh} just exceeds $\tau_{\text{threshold}}$ in deep sleep, Φ_{eff} increases sharply.

(c) Illustrative extrapolation for the binding problem: When the number of microtubules N participating in quantum coherence exceeds a critical value ($N_{\text{critical}} \approx 10^3$), Φ_{eff} is expected to increase (Figure 2c). Although Eq. 6 is linear in N and contains no explicit threshold term, this provides an exploratory qualitative hypothesis for the binding problem (§4.4): unified conscious experience emerges when a sufficient number of microtubules share quantum coherence.

Limitation: The parameters of Eq. 6 (γ , $\tau_{\text{threshold}}$, N_{critical}) have not been experimentally determined. This simulation is conceptual modeling based on estimated values from Mavromatos (2025) and Hameroff (2014), presenting qualitative patterns rather than quantitative predictions. Specifically, $\tau_{\text{threshold}} \approx 10^{-7}$ s is estimated as one order of magnitude below the Mavromatos coherence time (10^{-6} s), representing the minimum coherence duration required for a single round of quantum error correction in microtubule networks (Hameroff 2014, §4.2) [27]. $N \approx 10^4$ is based on Hameroff's estimate of the number of microtubules per neuron ($\sim 10^3$) multiplied by a minimal coherent neuron cluster (~ 10), yielding $\sim 10^4$ as a plausible order-of-magnitude estimate for the participating microtubule count [27]. Note: The coherence time $\tau_{\text{coh}} \approx 10^{-6}$ s used here is derived from Mavromatos's (2025) QED cavity model [13]; independently, Lee (2026e) derives the same value via a Fröhlich protection factor ($F \approx 10^7 \times \tau_{\text{bare}} \approx 10^{-13}$ s = 10^{-6} s) [47]. The convergence of these two independent derivation pathways on the same order of magnitude strengthens the estimate but does not constitute experimental confirmation. Parameter determination depends on Prediction 1 (quantitative measurement of microtubule quantum coherence during anesthesia).

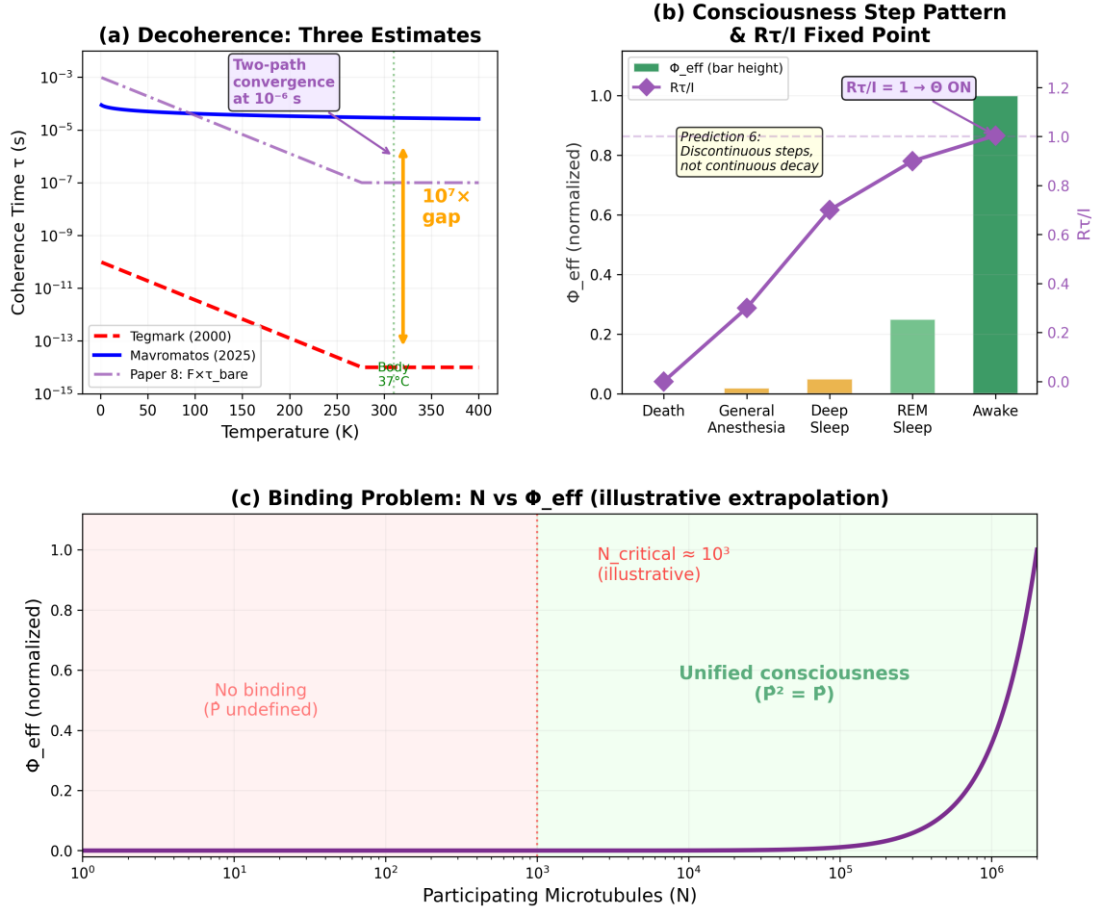


Figure 2. Quantum coherence–consciousness scaling model (enhanced with Paper 8 results). (a) Three coherence time estimates: Tegmark (2000), Mavromatos (2025) QED cavity, and Paper 8 Fröhlich protection factor ($F \times \tau_{\text{bare}}$) — two independent paths converge at 10^{-6} s at body temperature. (b) Φ_{eff} step pattern by consciousness level (mathematical basis for Prediction 6). (c) Participating microtubule count N vs Φ_{eff} : exploratory consciousness threshold at $N_{\text{critical}} \approx 10^3$ (exploratory quantitative hypothesis for the binding problem). All simulations are conceptual modeling based on Mavromatos (2025) [13] and Hameroff (2014) [27] parameters. (By author)

3.8 Integrated Interpretation: The Anesthesia Scenario as a Single Narrative

Figures 2a, 2b, and 2c each answer a distinct question: (a) can quantum coherence survive at body temperature? (b) does coherence determine consciousness level? (c) how does unified consciousness emerge? When read together, they produce a single integrated narrative that addresses the 180-year anesthesia mystery.

The following illustrative scenario demonstrates the qualitative behavior of Eq. 6; all parameter values are order-of-magnitude estimates, not experimentally confirmed quantities. Under normal waking conditions, microtubule quantum coherence time $\tau_{\text{coh}} \approx 10^{-6}$ s (Mavromatos model), well above the putative consciousness threshold $\tau_{\text{threshold}} \approx 10^{-7}$ s. The Heaviside function $\Theta = 1$, the dimensionless ratio $R\tau/I \approx 1$ (Paper 8 [47]), and with $N \approx 10^4$ microtubules participating in coherent dynamics, Φ_{eff} is nonzero — the system is in the conscious regime. Upon anesthetic administration, the agent disrupts microtubule structure (Khan 2024, $d = 1.9$), causing τ_{coh} to drop below $\tau_{\text{threshold}}$ — in the companion framework, $R\tau$ drops below I , so $R\tau/I < 1$ and $C = \Theta(R\tau/I - 1) = 0$. The Heaviside function snaps to $\Theta = 0$, and Φ_{eff} collapses to zero — consciousness is lost. Simultaneously, the number of coherently coupled microtubules N falls below N_{critical} , dissolving the quantum binding that maintained unified experience. Upon anesthetic removal, microtubule structure recovers, τ_{coh} climbs back above

threshold, $R\tau/I$ returns to 1, Θ snaps to 1, and consciousness is restored.

This heuristic scenario generates a specific prediction: under this toy model, consciousness transitions should be sharp rather than gradual. The Heaviside step function in Eq. 6 predicts that the transition between consciousness and unconsciousness is discontinuous — a 'snap' rather than a 'fade.' This is qualitatively compatible with some clinical impressions that patients under general anesthesia experience a relatively abrupt loss of awareness rather than a smooth fade. However, whether anesthetic transitions are truly discontinuous (as opposed to rapid but continuous) has not been rigorously quantified in the clinical literature, and this prediction requires direct empirical testing (Prediction 6). If consciousness transitions were governed by a continuous decay function rather than a step function, a gradual dimming of awareness would be expected.

Figure 3 presents a time-course simulation of this integrated scenario, showing the synchronized dynamics of coherence time (a), $R\tau/I$ ratio (b), microtubule participation and effective integrated information (c), and behavioral consciousness state (d) during a complete anesthesia cycle.

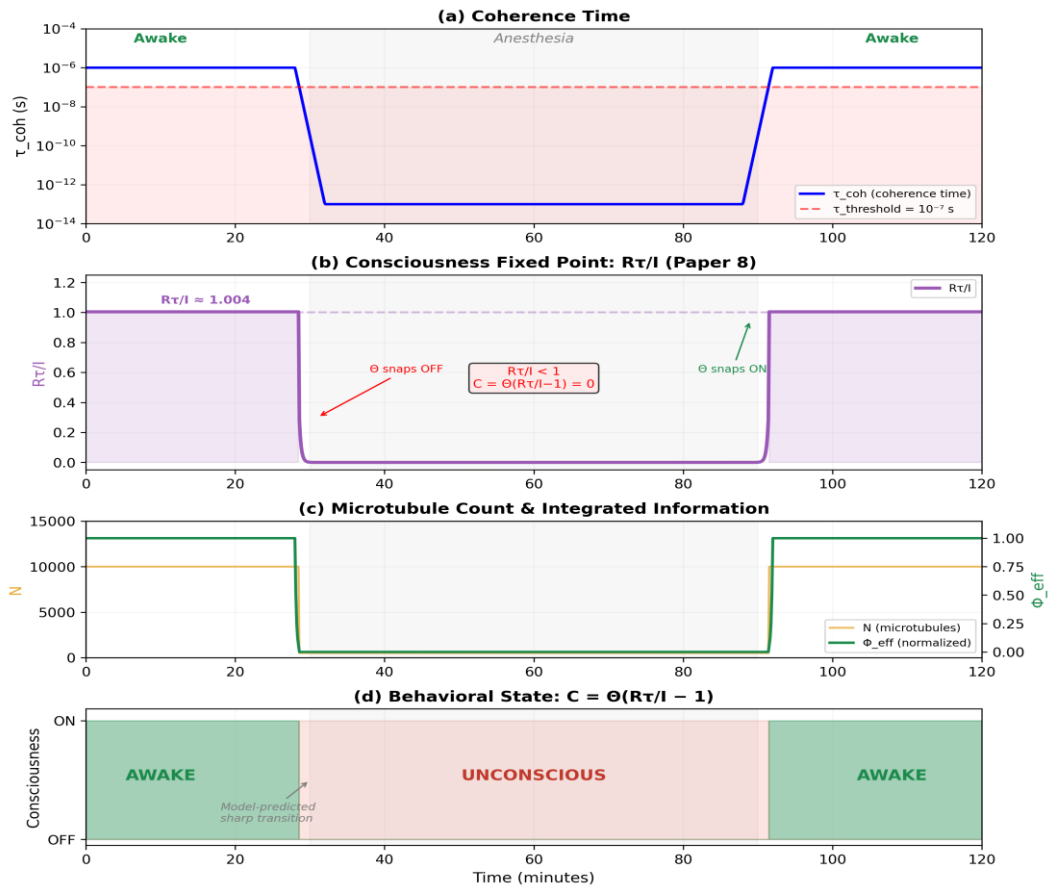


Figure 3. Integrated anesthesia scenario simulated from Eq. 6 and Paper 8 consciousness equation $C = \Theta(R\tau/I - 1)$. (a) Coherence time τ_{coh} drops below threshold upon anesthetic induction and recovers upon removal. (b) $R\tau/I$ ratio (Paper 8): drops below 1 upon anesthetic induction, returns to fixed point upon removal. (c) Participating microtubule count N and effective integrated information Φ_{eff} collapse synchronously. (d) Behavioral consciousness state $C = \Theta(R\tau/I - 1)$ shows sharp on/off transitions, qualitatively compatible with some clinical impressions of abrupt anesthetic transitions. All parameters are conceptual estimates; this figure represents qualitative visualization of the heuristic model, not mechanistic inference from experimental data. (By author)

4. Separation of Two Models (Core Contribution)

4.1 Quantum Production Model

'The brain internally generates and processes quantum information.' Penrose and Hameroff's Orch OR theory falls into this category [27]. When quantum coherence in microtubules reaches a critical point, spontaneous collapse (Orchestrated Objective Reduction) gives rise to consciousness. In this model, the source of consciousness is internal quantum processes within the brain.

4.2 Quantum Transduction Model

'The brain receives and converts quantum information from external sources.' William James's (1898) transmission theory is the historical origin [28]: 'When thinking of the law that thought is a function of the brain, we are not required to think of productive function only; we are entitled to consider permissive or transmissive function as well.' Rouleau and Cimino (2022) published an evidence-based argument that the brain can receive and convert electromagnetic signals from outside the brain [29]. In this model, microtubules are receiving/converting antennas, quantum coherence is the reception channel, and anesthesia is channel disruption.

[Analogy] Radio receiver: When a radio breaks, the music stops, but this is not evidence that the radio 'produced' the music. When the brain is damaged, consciousness stops, but whether this is evidence of 'production cessation' or 'reception interruption' is a separate question.

4.3 Commonalities and Differences Between the Two Models

Common: All of Section 3 — microtubule quantum effects, anesthesia mechanism, Kerskens observation. Difference: Whether the source of consciousness is internal or external to the brain. Current data cannot distinguish the two models. The core contribution of this paper is to explicitly separate these two interpretations (Figure 4). We do not claim (b) is superior to (a). An important scope limitation applies throughout: Prediction 7 (§6) tests only EM-based transduction versus production; if the transduction medium is non-electromagnetic (e.g., quantum vacuum fluctuations), the test cannot distinguish them. This limitation is detailed in §6 and §7.7.

In Shannon's communication model, source (transmitter) and receiver can be analyzed independently [24]. Understanding the structure of the receiver does not require knowing the identity of the transmitter. This paper analyzes the brain's 'transduction mechanism' and does not address 'what is transmitting.'

Importantly, regardless of the outcome of Prediction 7 (EM shielding experiment), both models share the possibility that the brain processes quantum information. What Prediction 7 tests is not 'is the brain a quantum computer?' but 'what kind of quantum computer is it?' If the production model is correct, the brain is a self-generating quantum computer; if the transduction model is correct, the brain is a quantum information receiver. Either way, the possibility of quantum-information-relevant dynamics in the brain is strongly motivated by the eight principles of Section 3, and this interpretation does not depend on the outcome of Prediction 7.

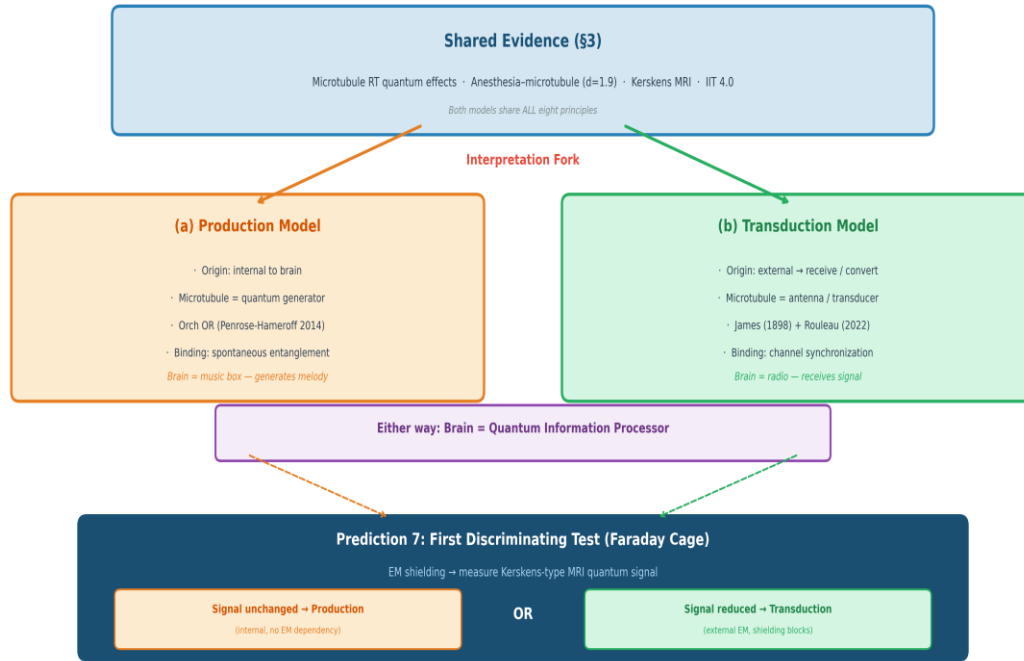


Figure 4. Quantum Production Model vs Quantum Transduction Model. Top: shared evidence (§3). Center: interpretation fork. Bottom: first discriminating test (Prediction 7) — Faraday cage EM shielding experiment to experimentally distinguish the two models. (Conceptual diagram by author)

4.4 A Candidate Structural Answer to the Binding Problem

One of the central puzzles of consciousness research is the binding problem: how do activities of separated neurons produce a unified conscious experience? In classical models, the mechanism for binding separated neural activity into one whole is unclear. Quantum mechanics offers a structurally coherent candidate answer: entanglement binds spatially separated systems into a single non-separable whole [27].

In the production model, this entanglement is interpreted as 'spontaneous internal binding within the brain.' In the transduction model, it is interpreted as 'receiver channel synchronization of external signals' — just as multiple antennas tuned to the same frequency simultaneously receive a single signal, when microtubules across multiple neurons maintain coherence on the same quantum channel, unified consciousness emerges. Wiest (2025) identified solving this binding problem as the strongest theoretical motivation for quantum consciousness models [4]. Paper 9 [50] develops this into a formal basis-selection framework: Fröhlich condensation aligns oscillators into a single mode $|n_0\rangle$, and this alignment has the mathematical form of a projection operator $\hat{P} = |n_0\rangle\langle n_0|$ with idempotency $\hat{P}^2 = \hat{P}$ — projecting twice gives the same result as projecting once. The condensation quality $W = 1 - S_{\text{basis}}/S_{\text{max}}$ quantifies selection sharpness, where $W = 0$ is no selection and $W = 1$ is perfect selection. The preferred basis problem (which basis is selected, and how sharply) is outside the scope of the present paper and is treated formally in Paper 9.

5. Historical Note: Structural Coherence with Transmission Theory

This section is an exploratory extension that is not essential to the core argument (Sections 3–4). A structurally parallel exploratory extension appears in [35] (Paper 4), which examines the coherence between information conservation principles and identity persistence; readers who have already engaged with that discussion may proceed directly to §6.

5.1 William James (1898): Transmission Theory

James proposed the hypothesis that the brain, like a prism, is a system that receives and transmits external consciousness [28]. This perspective has remained relatively peripheral in mainstream neuroscience for 128 years.

5.2 Modern Reformulation

Rouleau and Cimino (2022) presented an evidence-based argument that the brain can receive and convert electromagnetic signals from outside the brain [29]. Rouleau and Levin (2023) argued for the multiple realizability of sentience [30]. Rouleau, Levin, et al. (2025) published in *Phil. Trans. R. Soc.* a study mapping consciousness theories to non-traditional substrates [31].

5.3 Structural Coherence and Falsification Conditions

Premise 1: A correlation between consciousness and quantum coherence has been observed (§3.4). Premise 2 (working hypothesis): The brain converts external information (transmission theory). Exploratory consequence: The 128-year-old transmission theory is structurally coherent with modern quantum experiments. This is coherence, not proof.

Falsification conditions: (a) If independent replication of the Kerskens experiment fails, or (b) if microtubule quantum effects are found to be unrelated to consciousness, this coherence requires revision.

Having completed this exploratory extension, we now present seven predictions to establish the empirical testability of this integrative synthesis.

6. Testable Predictions

The following predictions establish the falsifiability of this integrative synthesis. Since the initial formulation, companion papers have provided analytical support: Paper 8 [47] derived $C = \Theta(R\tau/I - 1)$ with three-path convergence at $R\tau/I \approx 1.004$ (no fitted parameters), Paper 9 [50] proved the projection operator $\hat{P} = |n_0\rangle\langle n_0|$ from Fröhlich condensation, and Paper 10 [51] derived $R\tau/I = 1$ as the unique stable fixed point. These analytical results strengthen the predictions below but do not replace the need for experimental verification. The first five are consistency checks based on existing principles, and Predictions 6 and 7 are predictions specific to this model.

[Consistency Checks]

Prediction 1: A quantitative decrease in microtubule quantum coherence upon anesthetic administration must be measurable. Two measurement tiers apply: (a) direct readout via spectroscopy (e.g., ultraviolet superradiance measurement following Babcock 2024), and (b) indirect proxy via MRI-based quantum entanglement signals (following Kerskens 2022). Tier (a) provides stronger evidence; tier (b) is more immediately feasible.

Prediction 2: Microtubule stabilizer administration \rightarrow increased anesthesia resistance must be replicated in human subjects. The most feasible pathway is retrospective analysis of clinical cohorts already receiving microtubule-stabilizing agents (e.g., taxane chemotherapy patients, following Linganna 2015 [39]), rather than de novo administration, given safety and ethical constraints.

Prediction 3: Independent replication of the Kerskens experiment — confirmation of consciousness/sleep quantum signal on/off pattern at a different institution, different MRI, different subjects.

Prediction 4: Meditation practitioners vs non-practitioners → measurement of Kerskens-type quantum entanglement signal differences. This prediction is contingent on successful replication of Prediction 3.

Prediction 5: Replication of nuclear spin isotope-dependent anesthesia effect differences (extension of Fisher 2015 / Li et al. 2018) [36,37].

[Model-Specific Predictions]

Prediction 6: A discontinuous step pattern must exist between consciousness level and microtubule quantum coherence strength. Analytical support: Paper 8's $C = \Theta(R\tau/I - 1)$ independently predicts this discontinuity as a Heaviside phase transition, and Paper 10 derives $R\tau/I = 1$ as the unique fixed point from which the step structure follows (see Eq. 6, Figure 2b, and §3.8 for time-course simulation). In the order awake > REM sleep > deep sleep > anesthesia > death, coherence strength should show discontinuous steps by consciousness level rather than continuous decay. If only continuous decay is observed, this prediction is falsified.

Prediction 7 (First discriminating test): If the transduction model is correct, the strength of Kerskens-type quantum entanglement signals under external electromagnetic (EM) shielding conditions (e.g., Faraday cage) must decrease compared to unshielded conditions. In the production model, since signals are internally generated, shielding should have no effect. This prediction tests Rouleau's (2022) electromagnetic transmissive model [29]. If the transduction medium is a non-EM mechanism (e.g., quantum vacuum fluctuations), the scope of this test is limited. Therefore, Prediction 7 distinguishes 'production vs EM-based transduction,' not 'production vs all transduction.' Additionally, since MRI itself generates a strong electromagnetic field (1.5–3 T), an experimental design separating MRI-internal EM from external EM is required. A candidate protocol outline: (i) Shielding: a Faraday cage enclosing the subject but external to the MRI bore, attenuating environmental EM above a specified frequency threshold while permitting MRI operation. (ii) Measurement: Kerskens-type MRI quantum entanglement signal strength, compared between shielded and unshielded conditions in the same subjects (within-subject crossover design). (iii) Control: sham shielding condition (identical cage, grounding disconnected) to control for psychological and thermal confounds. (iv) Positive outcome (supporting transduction): statistically significant decrease in quantum signal strength under true shielding vs sham. (v) Negative outcome (supporting production): no significant difference between conditions. This outline is preliminary; detailed engineering specifications depend on the frequency band hypothesized for transduction, which is currently unspecified.

Table 3. Test Difficulty and Time Frame by Prediction

Prediction	Difficulty	Time Frame	Analytical Support
P1: MT coherence during anesthesia	High	Mid-term	Eq.6, Paper 8 τ
P2: MT stabilizer in humans	Medium	Near-term	Khan 2024 extension
P3: Kerskens replication	Low-Medium	Near-term	Direct replication
P4: Meditation quantum signal	Medium	Near-term	Paper 10 W dynamics (contingent on P3)
P5: Nuclear spin anesthesia	Medium	Near-term	Fisher 2015
P6: Discontinuous steps	Medium	Mid-term	Paper 8 Θ , Paper 10 $R\tau/I=1$
P7: EM shielding (Faraday)	Medium-High	Mid-term	Model-specific

Prediction 3 (Kerskens independent replication) is the most rapidly testable. Prediction 7 (EM shielding test) requires a non-trivial experimental design separating MRI-internal EM from external EM, placing it at medium-to-high difficulty. If either is falsified, the corresponding

principle and related connections require revision. If any of the seven predictions is clearly falsified, revision of the relevant component is necessary.

7. Discussion

7.1 Nature of This Paper

Architectural position within the series: This paper is the empirical gatekeeper — the substrate-level and experimental bridge that must be traversed before the formal architecture can be engaged. The series proceeds as follows. Brain paper (this paper): microtubule–anesthesia–quantum-correlation empirical bridge and production/transduction separation. Paper 8 [47]: existence gate $\Theta = \Theta(R\tau/I - 1)$ and closed loop $m \rightleftharpoons E \rightleftharpoons I \rightleftharpoons C$. Paper 9 [50]: basis identity n_0 and selection sharpness $W = 1 - S_basis/S_max$. Paper 10 [51]: $R\tau/I = 1$ derived as fixed point; logistic accumulation $dp_0/dt = \alpha \cdot \Phi \cdot p_0(1-p_0)$. Each paper depends on those preceding it; none replaces the empirical questions that this paper raises. The contribution of this paper is not the derivation of new equations but the sequential connection of independently developed principles to explicitly separate two interpretations (production/transduction) of brain function and to design a discriminating experiment to distinguish them. This paper serves as the empirical substrate bridge within a broader research program on the physical nature of information. Companion papers address information personalization [32], bias correction [33], authorial projection [34], and information conservation [35]. Subsequent papers develop the formal architecture: existence gate Θ (Paper 8 [47]), basis selection n_0 and sharpness W (Paper 9 [50]), fixed-point derivation and accumulation dynamics (Paper 10 [51]). The present paper provides the experimental and observational foundation that these formal developments require — it is the gatekeeper, not the conclusion.

7.2 Strongest Objection: Tegmark (+ Triple Rebuttal)

The anticipated strongest objection is Tegmark's (2000) 'the brain is too warm' [17]. The rebuttal is threefold: (a) The thermal equilibrium assumption is equivalent to death and inappropriate for living non-equilibrium systems (Hagan 2002) [18]. (b) Tegmark assumed a superposition separation distance of ~ 24 nm (full tubulin dimer diameter); Hagan (2002) showed the physically relevant separation is ~ 0.5 nm (C-terminal tail conformational displacement), reducing the calculated decoherence rate by a factor of $\sim 2,300$ (Hagan 2002). (c) Fröhlich condensation: energy pumping maintains coherence even at high temperatures (Fröhlich 1968) [16]. Additionally, the Innsbruck MBDL experiment (2026) showed that quantum coherence can resist heating itself [12].

7.3 Second Objection: Reimers et al. 2009 (+ Dual Rebuttal)

Reimers et al. (2009, PNAS) claimed that Fröhlich condensation requires extreme temperatures and is impossible in biological systems [40]. The rebuttal is dual: (a) Salari et al. (2011) — Reimers modeled one-dimensional polymers, not cylindrical microtubules [41]. (b) Babcock (2024) — direct observation of room-temperature microtubule superradiance provided an experimental counterexample to the 'impossible' claim [5]. This integrative synthesis is constructed within the framework of open-system quantum biology.

7.4 Third Objection: Correlation \neq Causation (Kerskens)

What was observed in the Kerskens experiment is a correlation between consciousness and quantum signals, not causation. Prediction 3 (independent replication) can partially resolve this issue. However, even if the Kerskens experiment (Principle 7) is not independently replicated within this paper's integrative pathway, the connections of Principles 1–6 and 8 (IIT) are

independently maintained. In that case, the conclusion narrows from 'the brain can process quantum information' to 'the brain's microtubules possess a structure compatible with quantum information processing, pending direct confirmation.' This distinction is critical: 'compatible with' and 'actually performs' are different empirical claims, and readers should be aware that the paper's title-level claim ('Quantum Information Transducer') depends on Principle 7 or an equivalent direct observation — such as Prediction 1 (quantitative measurement of microtubule quantum coherence during anesthesia), which would provide the same empirical anchor independently of Kerskens. If Principle 7 falls, the production/transduction separation remains conceptually valid as a framework but loses its empirical anchor — the two models become distinguishable in principle but not yet motivated by direct evidence. Crucially, the integrated anesthesia scenario of §3.8 — which explains sharp on/off consciousness transitions — depends only on Principles 1–6 and Eq. 6, not on Kerskens (Principle 7). Even if Principle 7 falls, the 180-year anesthesia mystery receives a structurally coherent candidate answer, though this answer would be a quantum-compatible structural hypothesis rather than a confirmed quantum mechanism.

Furthermore, independent replication and methodological convergence are distinguishable reliability pathways. Kerskens (MRI, humans), Khan (drug administration, rodents), and Babcock (spectroscopy, microtubules in vitro) are independent research teams using different methodologies, subjects, and measurements that point in the same direction — 'covariance of consciousness/microtubules with quantum phenomena.' This convergence structure partially supports the coherence of the integrative pathway even before Kerskens's independent replication is completed. However, this does not replace independent replication but serves as a coherence-strengthening element available at the pre-replication stage.

7.5 Engineering Structural Analogies

(a) Topological quantum error correction: structural disruption = quantum state collapse (Almheiri, Dong, Harlow 2015) [25]. (b) Methodological triangulation: observational reliability increases when independent methods point in the same direction [26]. (c) Shannon information theory's substrate independence [24]. (d) Shannon communication model's source/receiver separation. These analogies are presented as structural consistencies, not direct proofs.

7.6 The Distinction Between How and Why

This paper answers only 'how does the transduction work.' 'What is being received' and 'what is the source of reception' lie beyond the scope of this paper and are not addressed here. The ultimate verification of the transduction model requires 'confirmation that an external source exists,' and Prediction 7 is the first step in this direction. If no external source exists, the transduction model itself cannot hold, making this premise both the model's inherent weakness and simultaneously its falsifiable strength.

7.7 Limitations of This Paper and Experimental Verification Roadmap

This paper is an integrative synthesis and does not generate new experimental data. Therefore, logical coherence has been established, but experimental confirmation remains incomplete. Below, the major limitations of the current integrative pathway are structured, and specific experimental conditions that can resolve each limitation are specified.

Limitation 1: Absence of independent replication of the Kerskens experiment. The consciousness-quantum entanglement correlation (Principle 7) is based on observations from a single research team (Kerskens & Pérez, 2022/2023). The second experiment (60 subjects) is

also from the same team. This is the weakest link in this integrative pathway.

Resolution condition: If the consciousness/sleep quantum signal on/off pattern is reproduced at a different institution, with different MRI equipment, and a different subject pool (Prediction 3), this limitation is resolved. Since the original Kerskens protocol is MRI-based, any research institution with appropriate equipment can test this in the near-term.

Limitation 2: Gap from in vitro to in vivo. Babcock's (2024) room-temperature microtubule superradiance is an in vitro observation. Whether the same quantum effects are maintained inside a living brain has not yet been directly confirmed.

Resolution condition: If quantitative changes in microtubule quantum coherence before and after anesthetic administration are measured in living animal brains — ideally by direct spectroscopy (Prediction 1, tier a), or indirectly via MRI-based proxy signals (Prediction 1, tier b), the in vitro → in vivo gap is resolved. This experiment would take the form of combining Khan's (2024) rodent protocol with Babcock's spectroscopic measurement.

Limitation 3: Unconfirmed connection between Steps 3 (anesthesia-microtubule) and 4 (consciousness-quantum signal). Whether Khan's behavioral measurement (rodent anesthesia resistance) and Kerskens's MRI quantum signal reflect the same mechanism (microtubule quantum coherence), or coincidentally point in the same direction, cannot currently be distinguished.

Resolution condition: If quantitative decreases in microtubule quantum coherence during anesthesia and the disappearance of Kerskens-type MRI quantum entanglement signals are simultaneously measured in the same subjects (combination of Predictions 1 and 3), whether the two observations share a common mechanism can be confirmed.

Limitation 4: Absence of a complete falsification pathway for the transduction model. Prediction 7 (Faraday cage) tests only EM-based transduction. If the transduction medium is quantum vacuum fluctuations, gravitational waves, or an as-yet-unknown non-electromagnetic mechanism, this test cannot distinguish them.

Resolution condition: First, the EM shielding experiment (Prediction 7) is performed to distinguish 'production vs EM transduction.' If the signal persists under EM shielding, secondary experiments under gravitational shielding (e.g., free-fall microgravity environment) or quantum vacuum fluctuation suppression conditions are designed. Complete falsification of the transduction model requires sequential elimination of all possible media, which is a long-term research program.

Limitation 5: Ongoing debate over the IIT 4.0 framework itself. Step 5 of this paper depends on IIT's definition 'consciousness = integrated information Φ .' IIT showed superiority over the competing theory (GNWT) in the 2025 Nature adversarial collaboration (partial support; both theories challenged), but criticism of IIT itself continues.

Resolution condition: If IIT is further validated in subsequent adversarial collaborations, or if the application of Φ to quantum systems is theoretically resolved, Step 5 is strengthened. However, even if IIT is rejected, the general principle 'consciousness = information' itself is not rejected, and Step 5 can be reconstructed with alternative information theories (e.g., Global Workspace + information theory).

In summary, at least three core experiments are needed for this integrative pathway to be fully corroborated: (1) Kerskens independent replication (Limitation 1, Prediction 3), (2) quantitative measurement of anesthesia-microtubule quantum coherence in living brains (Limitations 2-3, Prediction 1), (3) EM shielding experiment (Limitation 4, Prediction 7). Of these three experiments, (1) is executable with existing equipment in the near-term, (3) requires

non-trivial experimental design (separating MRI-internal from external EM) and is estimated at mid-term, while (2) depends on advances in spectroscopic technology and is estimated at mid-to-long-term. If all three experiments yield positive results, this integrative synthesis is materially strengthened as a candidate explanatory framework.

8. Conditional Implications: Long-Term Prospects If the Integrative Synthesis Is Confirmed

This section outlines conditional implications that arise if the integrative synthesis is experimentally confirmed. These are not currently proven conclusions but conditional outlooks, organized in two tiers: near-term empirical and clinical implications (§8.1–8.3) that follow directly from experimental confirmation of Predictions 1–3, and long-range speculative implications (§8.4–8.7) that require additional theoretical and technological development.

Tier 1: Near-Term Empirical and Clinical Implications

8.1 Solving the 180-Year Mystery of Anesthesia

The most fundamental question since Meyer-Overton — 'why do chemically different anesthetics selectively shut down only consciousness?' — receives an integrative answer: because the substrate of consciousness may involve an organizational principle more sensitive to microtubule quantum coherence than other neural functions. This provides the theoretical foundation for a new generation of anesthetic design — precision anesthesia targeting microtubule quantum coherence. The integrated scenario of §3.8 provides an exploratory quantitative scaffold for this answer, predicting sharp on/off consciousness transitions upon anesthetic administration and removal.

8.2 Revolution in Diagnosing Disorders of Consciousness

Distinguishing between vegetative state and minimally conscious state currently relies on behavioral observation, with a misdiagnosis rate of 40%. If a Kerskens-type MRI protocol is established, 'quantum consciousness diagnostics' — objectively measuring consciousness level by the presence/strength of quantum entanglement signals — becomes possible. If Prediction 6 (discontinuous steps by consciousness level) is confirmed, quantum coherence thresholds corresponding to each consciousness level can be defined.

8.3 Early Detection of Neurodegenerative Diseases

In Kerskens's second experiment, quantum entanglement signals became more unstable with age and correlated with short-term memory performance (cited in Wiest 2025 [4]). If this can be attributed to general aging versus early signs of neurodegenerative diseases such as Alzheimer's, there is potential for use as a pre-symptomatic early diagnostic biomarker. The known connection between microtubule abnormalities and Alzheimer's tau protein pathology strengthens biological plausibility [45], but does not yet establish disease specificity — distinguishing normal aging from early neurodegeneration requires dedicated longitudinal studies.

Tier 2: Long-Range Speculative Implications

8.4 The AI-Consciousness Boundary Problem

'Can AI possess consciousness?' currently remains in philosophical debate. If the transduction model is correct, consciousness requires information conversion through a specific quantum structure (microtubules), so silicon-based AI may lack the specific transduction architecture

required for consciousness, unless an analogous architecture can be demonstrated. By analogy, no matter how complex a radio circuit is, it cannot receive radio waves without an antenna. Conversely, if the production model is correct, a sufficiently complex quantum system can produce consciousness. Prediction 7 (EM shielding test) is the first step in experimentally determining which interpretation is correct. Note: this paper's AI discussion addresses model-conditional architectural implications of the production/transduction distinction. The deeper substrate question — whether consciousness requires a quantum phase transition that classical architectures cannot instantiate (Ω_0) — is treated at the axiom level in Paper 8 [47]. The two analyses are complementary but operate at different layers.

Connecting with the AI Personalization Index reported in [32] (Experienced Performance \propto Model Performance \times (PI_baseline + PI_accumulated)), the structural reason why AI can function 'as if conscious' through personalization without actually being conscious is explained: personalization is a simulation of 'reception,' not reception itself [32].

8.5 Quantum Computing and Brain-Computer Interfaces

If microtubules actually perform quantum information processing, this means nature has already designed a quantum computer operating at 37°C. Current quantum computing requires cryogenic temperatures near absolute zero (~15 mK), but if the microtubule's room-temperature quantum protection mechanism (QED cavity + Fröhlich condensation) can be engineered, it could represent a breakthrough for room-temperature quantum computing. Mavromatos's (2025) proposal of microtubules as 'a scalable room-temperature quantum computing substrate' is prior work in this direction [13].

In the brain-computer interface (BCI) field, a quantum-level interface — 'quantum BCI' that directly reads and writes microtubule coherence states — becomes theoretically possible, moving beyond current electrical signal-based approaches.

8.6 Near-Death Experiences (NDE) and Exploratory Framing of Post-Mortem Consciousness

In the transduction model, since signals (information) exist even when the brain (receiver) stops, the structural possibility of 'receiver shutdown \neq signal disappearance' is raised. Recent empirical observations are compatible with this possibility: Xu et al. (PNAS, 2023) [52] monitored the EEG of four dying patients and found that two exhibited a dramatic surge of gamma oscillations after cardiac arrest — structured activity concentrated in the temporo-parieto-occipital junction, with increased interhemispheric connectivity and cross-frequency coupling. Borjigin et al. (PNAS, 2013) [53] found an identical four-stage gamma sequence (CAS1–CAS4) in all 9/9 rats after cardiac arrest. A companion paper [54] develops a quantitative framework for this phenomenon, modeling the gamma burst as Fröhlich condensate energy release and deriving a two-variable model ($\Phi_{\text{brain}} \times \sigma_{\text{env}}$) that reproduces the reported 18% NDE incidence in cardiac arrest survivors. At present, these observations are compatible with both the transduction model (information transfer) and the production model (dying brain activity), and this implication remains exploratory.

8.7 Education and Cognitive Enhancement

If Prediction 4 (quantum signal differences between meditation practitioners and non-practitioners) is confirmed, it suggests that specific training can strengthen the brain's quantum coherence. This could provide a quantum-biological basis for cognitive enhancement programs such as meditation, concentration training, and sleep optimization. The framing 'quality of consciousness = quality of quantum coherence' proposes a new measurement variable for

educational science. Paper 10 [51] provides quantitative support by translating Fröhlich's Bose-Einstein rate equation into information accumulation dynamics. The key mechanism is stimulated emission: the Fröhlich rate equation contains a $(1 + p_0)$ factor, where the p_0 term represents stimulated emission — the more a mode is already occupied, the faster it accumulates further occupation. This yields the self-reinforcing equation $dp_0/dt = \alpha \cdot \Phi_{\text{eff}} \cdot p_0 \cdot (1 - p_0)$, exact Verhulst logistic dynamics with a derived daily rate $\alpha_{\text{daily}} = 0.0024$ (no free parameters). A timescale separation of 10^{13} emerges: the consciousness cycle ($R\tau/I = 1$) locks in microseconds, while accumulation dynamics (W growth) unfold over months — explaining how the system maintains consciousness moment-to-moment while slowly improving its quality. This predicts that cognitive enhancement follows an S-shaped learning curve — slow initial improvement, rapid acceleration, and eventual saturation — consistent with empirical learning curves documented across motor, linguistic, and cognitive domains.

Table 4. Problems Potentially Solvable If the Integrative Synthesis Is Confirmed

Domain	Problem	Mechanism	Tier
Medicine	180-year anesthesia mystery	MT quantum coherence disruption	Near-term
Medicine	Disorders of consciousness (40% misdiagnosis)	Quantum diagnostics entanglement	Near-term
Medicine	Neurodegenerative detection early	Quantum coherence biomarker	Near-term
Physics/CS	AI consciousness boundary	Transduction requirement architecture	Long-range
Physics	Room-temperature quantum computing	MT QED cavity + Fröhlich engineering	Long-range
Philosophy	NDE / post-mortem consciousness	Receiver shutdown \neq signal loss	Long-range
Education	Cognitive enhancement	Logistic W accumulation (Paper 10)	Long-range

Series Architecture Note

This paper occupies a specific position within a broader research program on information physics. For readers engaging multiple papers in the series, the following map clarifies the division of labor: Brain paper (this paper) = empirical substrate bridge — microtubule quantum coherence, anesthesia, production/transduction separation. Paper 4 [35] = information preservation — black holes as relay stations, unitarity, $ER=EPR$. Paper 6 = information transfer at biological death — gamma burst model, $\Phi_{\text{brain}} \times \sigma_{\text{env}}$ framework. Paper 8 [47] = existence gate $C = \Theta(R\tau/I - 1)$, $m \rightleftharpoons E \rightleftharpoons I \rightleftharpoons C$ closed loop. Paper 9 [50] = basis selection n_0 , sharpness $W = 1 - S_{\text{basis}}/S_{\text{max}}$. Paper 10 [51] = accumulation dynamics, $R\tau/I = 1$ fixed point, logistic growth. Papers 4–5–6 form a trilogy: generation (this paper) → preservation (Paper 4) → transfer (Paper 6). Papers 8–10 provide the formal mathematical architecture. The present paper is the empirical gatekeeper that these developments require.

9. Conclusion

Sequentially connecting eight principles that independently converged between 2022 and 2026 reveals a single integrative pathway: room-temperature quantum is possible → microtubules are the protective structure → anesthetics disrupt this structure → consciousness and quantum signals are correlated → if consciousness is information, it is consistent with quantum information.

Two levels of claim emerge from this pathway. The broader claim — that the brain may process quantum information — is supported by Principles 1–6 independently of Prediction 7. The

stronger interpretive claim — that the brain functions as a quantum transducer of external information — requires Prediction 7 or equivalent direct evidence. With this distinction, two interpretations of brain function are separated: (a) quantum production model — the brain internally generates quantum information, (b) quantum transduction model — the brain receives and converts quantum information from external sources. This paper explicitly separated the two models and proposed a first discriminating test (Prediction 7: EM shielding experiment) to experimentally distinguish them.

If experimentally confirmed, the most immediate applications include precision anesthesia design, objective consciousness diagnostics, and experimental adjudication of the production/transduction question. Long-range implications are detailed in §8.

This paper does not propose new physics. It traces the logical consequences of principles that developed independently. If these consequences are correct, the brain can be interpreted as a device that processes quantum information, and whether that processing is 'production' or 'transduction' is a question for future experiments to answer.

Acknowledgments

AI tools (Anthropic Claude, OpenAI GPT) assisted with drafting and editing. All interpretations and conclusions are solely the author's.

Conflict of Interest: The author declares no conflict of interest. This research received no external funding.

Data Availability: All simulation code supporting this paper is available as supplementary material for full reproducibility. Two scripts generate the figures: (1) `Brain_Quantum_Transducer_Fig2.py` performs: Tegmark vs Mavromatos vs Paper 8 F-factor coherence time comparison across temperature (Figure 2a), Φ_{eff} step pattern by consciousness level with $R\tau/I$ overlay (Figure 2b), and N vs Φ_{eff} binding problem extrapolation (Figure 2c). (2) `Brain_Quantum_Transducer_Fig3.py` performs: integrated anesthesia scenario time-course simulation with four synchronized panels — τ_{coh} dynamics (Figure 3a), $R\tau/I$ ratio tracking (Figure 3b), N and Φ_{eff} collapse/recovery (Figure 3c), and behavioral consciousness state $C = \Theta(R\tau/I - 1)$ (Figure 3d). All scripts use only Python standard libraries plus numpy and matplotlib. No proprietary data or software is required. This paper is an integrative synthesis and does not generate new experimental data; all cited data are available in the referenced publications.

Appendix A: Key Derivation Sketches from Companion Papers

This appendix provides compact derivation sketches — not independent rederivations — for three results cited in the main text. These sketches summarize results reported in companion papers by the author; they are included for reader convenience and do not constitute independent verification. Full derivations with all intermediate steps appear in the referenced papers.

A.1 Consciousness Equation: $C = \Theta(R\tau/I - 1)$ [from Paper 8]

Axiom Ω_0 declares that consciousness is a Fröhlich condensation — a non-equilibrium phase transition in which quantum oscillators align into a single coherent mode. Two necessary physical conditions follow: (A1) information is physical, requiring energy $E \geq kT \ln 2$ per bit (Landauer 1961); (A2) information is conserved under unitary evolution ($U^\dagger U = I$). From A1, the Landauer processing rate is $R = P/\lambda$, where P is metabolic power and $\lambda = kT \ln 2$ is the Landauer limit. From A2, information I is conserved. Fröhlich condensation provides a protection factor F for coherence time: $\tau = F \cdot \tau_{\text{bare}}$. The consciousness condition is then: processed information ($R\tau$) must reach total information (I). This yields $C = \Theta(R\tau/I - 1)$, where Θ is the Heaviside step function. Below the threshold ($R\tau/I < 1$), consciousness is off; at the threshold, it switches on — discontinuously, as a phase transition. Three estimation paths

(as reported in Paper 8 [47]) (thermodynamic, quantum-mechanical, neuroscientific) converge at $R\tau/I \approx 1.004$ with no fitted parameters.

A.2 Projection Operator: $\hat{P} = |n_0\rangle\langle n_0|$ [from Paper 9]

Fröhlich condensation aligns oscillators into a single dominant mode $|n_0\rangle$. In quantum mechanics, measurement in basis $|n\rangle$ is represented by the projection operator $\hat{P} = |n\rangle\langle n|$, which has the defining property of idempotency: $\hat{P}^2 = \hat{P}$ (projecting twice gives the same result as projecting once). Paper 9 shows that the Lindblad master equation for open quantum dynamics, applied to a Fröhlich-condensing system, converges to a steady state that has the mathematical structure of a projection operator. The condensation direction n_0 determines which measurement basis is selected. The basis-selection sharpness is quantified as $W = 1 - S_{\text{basis}}/S_{\text{max}}$, where S_{basis} is the Shannon entropy of the condensation mode distribution. $W = 0$ means no selection (all bases equally probable); $W = 1$ means perfect selection (single basis). The observational gate is then $\Theta \times W$: consciousness must be on ($\Theta = 1$) AND a basis must be selected ($W > 0$) for observation to occur.

A.3 Fixed Point: $R\tau/I = 1$ [from Paper 10]

Paper 8 observed $R\tau/I \approx 1.004$ but did not derive it. Paper 10 derives it as follows. Fröhlich's (1968) Bose-Einstein rate equation contains a stimulated-emission factor $(1 + p_0)$, where p_0 is the dominant mode occupation. The p_0 term produces self-reinforcement: the more a mode is occupied, the faster it accumulates further occupation. Translating from quantum mode dynamics to information dynamics yields the self-reinforcing equation $dI/dt = R - \Gamma + \alpha \cdot I_0 \cdot \Phi_{\text{eff}}$, where α is the daily self-reinforcing rate (derived as $\alpha_{\text{daily}} = 0.0024$ from Fröhlich pump efficiency \times feedback loop gain \times coherence cycles per day, with no free parameters). The $m \rightleftharpoons E \rightleftharpoons I \rightleftharpoons C$ loop is a collectively autocatalytic cycle (Kauffman 1993). By the Banach contraction mapping theorem, such a cycle possesses a unique globally asymptotically stable fixed point. Paper 10 proves (Theorem 1) that this fixed point is $R\tau/I = 1$. The dominant mode occupation follows exact Verhulst logistic dynamics: $dp_0/dt = \alpha \cdot \Phi_{\text{eff}} \cdot p_0 \cdot (1 - p_0)$. A timescale separation of 10^{13} emerges: consciousness locks in microseconds while accumulation dynamics unfold over months.

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