Original Research

# Quantum-delocalized information systems in the brain: nonclassical pathways to the emergence of consciousness

R.R. Poznanski[1,*], O. Pusuluk[2], and C.H.Raymond Ooi[3]

[1] BION Institute, SI-1000 Ljubljana, Slovenia
[2] Faculty of Engineering and Natural Sciences, Kadir Has University, Istanbul 34083, Turkey
[3] Department of Physics, Universiti Malaya, Kuala Lumpur 50603, Malaysia

***Correspondence**: romanrpoznanski@gmail.com
DOI: https://doi.org/10.56280/1699258685



Received: 21 March 2025 Accepted: 15 May 2025 Online Published: 3 June 2025

**Abstract**

This paper presents a theoretical model proposing that quasiparticle-mediated proton ($H^+$) dynamics, modulated by dipolar excitations across π-conjugated organic molecules, specifically at amphipathic membrane proteins and interfaces, give rise to emergent hybrid modes—termed tripartite quasipolaritons—under nonequilibrium steady-state conditions. These modes arise from light-matter-vibration coupling dynamics. Quasiparticle-mediated proton dynamics within the hydrophobic pockets of amphipathic complexes occur through their non-closure under nonequilibrium steady-state conditions. We explore how quantum optical effects facilitate light-matter interactions, enhancing photoprotection, involving vibrational modes when anti-entropic conditions prevail for delocalized π-excitations while maintaining conserved epistemic quantum entropy. Dipolar excitations through patterns of energetic uncertainties play a role in establishing the conditions needed for a unified and interconnected informational system of photon pathways in aromatic amino acid residues. This system is proposed to link localized biochemical processes involving π-$H^+$ interactions and π-π stacking of amino acids in neuroproteins with the coupling dynamics that give rise to quantum optical effects. Quantum-delocalized information systems, which involve the interplay between π-electron dynamics, localized electromagnetic fields, and proton interactions, establish a quantum-level connection between light-matter interactions and memory encoding mechanisms. This may provide pathways through which intrinsic quantum phenomena, such as quantum memory, directly contribute to consciousness by enabling the action selection mechanism in quantum-delocalized systems. Our model proposes that such systems may underlie consciousness, supported by the quantum architecture of the multiscale brain. This framework uncovers a previously hidden mechanism for the interconnectedness of informational pathways between amino acids in proteins and among neural protein networks within and across neuropil microcavities, revealing a quantum foundation for functional unity.

***Keywords***: Consciousness, quantum emergent physicalism, quantum proton delocalization, π-conjugated amino acids, π resonance dipoles, amphipathic complexes, neuropil microcavities, quasipolaritons, epistemic quantum entropy, entropic pilot waves, anti-entropic condition, Madelung hydrodynamics, optical resonance, structure process.

## 1. Introduction

Any theory of higher brain function that addresses consciousness must be grounded in biophysical and biochemical plausibility, as emphasized by Edelman (1979). While consciousness theories such as Orch OR model attempt to explain quantum aspects of consciousness (Hameroff & Penrose, 1996), they lack a viable substrate for consciousness, given that microtubule destabilization is not a direct cause of disruption of functional 'unity'. In some of his later work, Hameroff (2006) emphasizes quantum interactions within microtubules but has been criticized for oversimplifying molecular mechanisms and for speculative interpretations of quantum (London) forces in biological systems. However, London forces do not directly have an effect on π-π interactions. Their role is in protein-protein interactions, which could potentially influence the functional 'unity' of consciousness. Hameroff suggests that aromatic amino acid units with π-resonance residues form dipoles through π-π stacking in nonpolar, hydrophobic regions of tubulin proteins. Anesthetics disrupt these dipoles by affecting London forces, implying that the π resonance dipoles are compromised. Overall, Hameroff's ideas (see Hameroff, 1987, 2022, for an overview) overlook a critical element: the presence of water molecules that may protect the π-π resonance (given that anesthetics are attracted to oil rings rather than water). This protection could allow the π resonance to persist even in the presence of anesthetics, enabling consciousness to return instantly once the anesthetics no longer influence the electrostatic interactions. The disruption of consciousness by anesthetics can also mean that the functional 'unity' of consciousness, is disrupted. This subtle difference explains why irreversible alteration to consciousness due to anesthesia does not occur and why consciousness does not simply disappear during general anesthesia (Montupil et al., 2023).

Hameroff (2021) later work diversified into a specific model of microtubules in the brain to be central for consciousness, as proposed in the "Orch OR" theory (Hameroff & Penrose,1996, 2014). They propose that consciousness may involve quantum processes at certain levels, particularly within structures like microtubules inside neurons. Microtubules orchestrate the collapse of quantum superpositions when a threshold is reached, giving rise to moments of conscious experience. The Orch OR model relies on coherent quantum dynamics but struggles to connect these dynamic processes to higher-order cognitive processes. Objective reduction introduces discrete moments of collapse, influenced by the geometry of physical spacetime, which leads to the collapse of the wavefunction. These discrete events of collapse are thought to be related to conscious moments or experiences. The Orch OR model also proposes that microtubule coherence may be protected from decoherence and could be long-lasting. This suggests that quantum coherence within microtubules is designed to persist, enabling entanglement formation. If coherence were too intermittent[1], with frequent collapses, it could disrupt entanglement before it fully manifests, highlighting a significant issue with the Orch OR model. Quantum coherence is necessary for the emergence of consciousness in earlier models of consciousness. However, "biological systems at room temperature normally have very strong decoherence, which destroys quantum superpositions (Tegmark, 2000).

Kerskens & Pérez (2022) reported multiple quantum coherences potentially linked to nuclear proton spins in *bulk water* molecules, proposed as a "witness" of quantum entanglement. Bulk water is also essential for protein turnover and enzymatic catalysis. However, it is misleading to consider it as a water laser (Del Giudence et al., 1988) based on quantum field theories. Superposition breaks down when there are interactions with the electromagnetic (EM) field, which means no quantum state can exist long enough to functionally support consciousness. The transition from quantum coherence to entanglement remains inconclusive (Gassab et al., 2025, for an overview). This is problematic, especially if it postulates that the 'unity' of consciousness originates from presumed quantum entanglement between microtubules (Hameroff & Penrose,1996) or between molecules (Fisher, 2015).

According to the above ideas, the brain may operate as a quantum system while remaining within a predominantly classical, macroscopic environment. However, when we adopt the view that consciousness operates as a classical system in a quantum environment, with most of its activity described by classical physics, yet is still fundamentally embedded within the quantum nature of the physical world. Therefore, other quantum effects, such as quantum delocalization and quantum tunnelling, are part of the information process (Gassab et al., 2025). The brain is primarily a classical system in that its everyday processes, such as neural signaling, cognition, and behavior, are governed by classical physics, including electromagnetism and chemistry. The neurons and synapses operate based on chemical reactions, ion flows, and electrical potentials, which can be described using classical models. At the fundamental level, the environment in which the brain operates is quantum in nature. The atoms, molecules, and quasiparticles in brain processes obey quantum mechanics. Quantum effects, such as superposition and quantum entanglement, play a role at the subatomic level in the interactions that shape the brain's behavior, especially when defining the quantum potential as a field. For instance. Jibu & Yasue (1995) proposed that *ordered water* at dendritic membrane surfaces undergoes Bose–Einstein condensation (BEC), forming a large-scale coherent quantum state. The BEC is both a coherent and a collective state because the coherence of the quasiparticles leads to their collective behavior, and this collective interaction gives rise to coherent phenomena—a defining feature of the condensate. One cannot exist without the other in the context of BECs. BEC is the collective behavior of photon quasiparticles that results in the system self-organizing into a stable state (e.g., Jibu et al., 1996; Georgiev, 2004). In previously published work by Jibu et al. (1996), it was proposed that an evanescent photon field (or soft polariton) is responsible for consciousness. It was theoretically proposed that microtubules may shield these effects (Jibu et al., 1994), and experimentally, it has been shown that energy transfer occurs (Kalra et al., 2023). Still, the electronic coupling between transition dipoles is weak (Babcock et al., 2024).

[1] Intermittent is a transient, recurring coherence rather than sustained at body temperature.

However, the collective quantum dynamic properties of the information process do not require BEC. In condensed matter physics, it is known that collective quantum dynamics can occur without coherence, relying on the interactions and energy transitions between quasiparticles (Manovitz et al., 2025), which leads to collective excitations. Energy exchanges can drive the transitions and interactions in collective dynamics. However, BEC requires coherence in the strict sense of phase alignment across all particles. Alternatively, collective quantum dynamics in molecular biophysics does not rely on quantum entanglement due to quantum decoherence in brain processes (Tegmark, 2000). In contrast, quantum collective dynamics can remain stable at much higher temperatures than those at which entanglement is lost. In molecular quantum systems, quantum collective dynamics can persist at elevated temperatures, potentially reaching physiological temperature. However, most traditional quantum collective phenomena, such as superconductivity, superfluidity, and BEC, are highly sensitive to temperature and typically break down at much lower temperatures than body temperature. Therefore, our quantum-based modeling is founded on thermo-quantum fluctuations, where quantum uncertainty is replaced with entropic stochasticity and can be sustained over a broader temperature range, specifically at physiological temperatures, approximately 310 K.

Still, it is suggested to capture consciousness's emergent nature, emphasizing that it is not a "thing" that can be pinned down to specific locations or mechanisms but an ongoing, information process that at the molecular scale relies on irregularities, for example, fluctuations as variations or changes that may or may not follow a regular pattern. They do not always form waveforms that are specific types of fluctuations that are periodic and regular, like those seen in traveling or standing waves. The quantum collective dynamic in molecular biophysics is not an *evanescent field* but is typically non-propagating and decays exponentially as it moves away from a boundary or surface of interfacial water and theoretically is grounded in principles of "dynamic organicity," where there is a continuous yet rapid flux of degradation in structure (Poznanski 2024a,b). All biological molecules undergo the process of dynamic organicity (Schoenheimer, 1942), including microtubules, so there is no permanent "protection" from the decoherence of a quantum state. Why dynamic organicity? Organic compounds are more likely to exhibit a unified emission involving electron delocalization**,** proton delocalization**,** and photon emission because of their chemical flexibility**,** conjugated systems**,** and proton-coupling abilities**.** Organic molecules, especially those in conjugated systems or hydrogen-bonded networks**,** are better suited for processes where electrons and protons can move together**,** facilitating photon emission upon relaxation. Inorganic systems, while capable of electron delocalization and photon emission, often do not exhibit the same level of proton delocalization and are less likely to display such unified emission unless specifically designed for these processes.

Addressing the root of consciousness through pharmacological means involves using agents that can cross the blood-brain barrier and disrupt the brain's dynamic organicity (the dynamic nature of conjugated organic molecules in the brain). Glioblastoma proliferation can damage neuroplasticity and lead to cognitive defects (Krishna et al., 2023). Loss of consciousness often occurs in the late stage of tumor progression, with death typically resulting from brain herniation due to tumor advancement (Sizoo et al., 2010). In treating glioma tumorigenesis, the efficacy of the drug ST-401 and its analogues—which can cross the blood-brain barrier and disrupt the functioning of microtubules at the colchicine binding site of tubulin (Horne et al., 2021) – is crucial. However, there is a lack of evidence on the effects of this agent on consciousness in patients diagnosed with glioma. Notably, despite these drugs affecting microtubules, they have not shown significant effects on consciousness, which is important evidence against theories proposing that microtubules play a central role in consciousness. Brain-penetrant microtubule-stabilizing agents, such as epothilone, have been demonstrated to delay the effects of anesthesia in rats (Khan et al., 2024). The study did not suggest that consciousness was lost when the agent was withdrawn before anesthesia, indicating no relevance to the mechanisms of consciousness. Although these drugs target microtubules and are used in cancer treatment, their impact on consciousness is limited.

Consciousness in action can be understood as an emergent biological phenomenon grounded in intentionality. This process relies on quantum potential energy, also referred to as the information potential. It enables formation from potential states without any external sources. Searle (1991) identifies intentionality as a distinguishing feature of consciousness, indicating that consciousness is constantly directed towards something. According to Searle (1991), intentionality is unconscious or precognitive, as it can be viewed as the result of a quasipolaritonic action that continuously selects uncertainties in energy, manifesting as intentionalities, allowing an organism to assign meanings independent of the environment. Intentionalities are not mere causal processes, like intentional states within the brain, but rather intrinsic facets of consciousness (Searle, 1991). This would suggest that conscious experience is rooted in a precise, 'hidden structure' that is actualized in the brain as a transition from potentialities to intentionalities, giving form to action through negentropic gain in shaping motion through informational pathways (Poznanski & Alemdar, 2024). While certain affective states may lack a specific intended referent, the "*affective drive*" establishes a connection between these affective states and intentional states that is postulated to stem from the hidden thermodynamic energy guided by entropic pilot waves (Poznanski et al., 2024).

Hameroff (1987) suggests that the brain is a continuous system. Continuity requires that the random processes of evolutionary change be mitigated through nonlinear mechanisms, such as dynamic organicity. In a continuous system, the behavior of the whole system is determined by the interactions of its components at every moment in time. This implies that continuous interactions within the brain predetermine the emergence of consciousness. In this context, superdeterminism would apply, as free will does not need to be probabilistic but can be driven by fluctuations. These fluctuations could influence how neural signals are transmitted simply by *multiscale dynamics* (Pesenson & Schuster, 2013). If these fluctuations interact with or modulate neural firing patterns, they could influence the patterns of cognition and perception, ultimately giving rise to conscious experience. Superdeterministic consciousness posits that free will emerges not from randomness but from nonlinear thermo-quantum fluctuations amplified through a quantum-delocalized information system, serving as the "unifying mechanism" that bridges the classical and quantum realms, thereby creating the illusion of choice and agency (Libet, 1999) and an apparent binding (Posner et al., 2007). This fluctuation-driven behavior could provide a source of variability for the brain's decision-making, referred to as 'entropic brain' (Poznanski & Alemdar, 2024), as it introduces an element of *uncertainty*, representing a multiscale version of fluctuation-driven intentionalities.

## 2. Photon dynamics in neuropil microcavities

The emission of biphotons at specific wavelengths is contingent upon the energy states of chemical bonds, as the emitted energy is typically either absorbed immediately or transmitted as ultraweak tunneling biophotons[2]. Spontaneous ultraweak biophoton emission is most prevalent during metabolic processing in the brain. However, evidence also supports photon entanglement in benzene moieties of fluorescent proteins (Shi et al., 2017). This phenomenon arises when the 10-stranded β-barrels, containing aromatic amino acid residues with resonant electron orbitals in nonpolar regions, are amphipathic proteins, and have a large hydrophobic continuous microcavity along the amphipathic structure. Hydrophobic regions play a role in quantum optical effects. When we discuss coupling hydrophobic pockets to form a continuous path, this typically refers to neuropil microcavities that can couple, merge, or align without closure, facilitating energy transfer and helping to focus photon energy in specific ways. While bulk water might be excluded, there may still be a small amount of interfacial water that exists near the surface of the hydrophobic pockets. This water is often structured and can still interact with the protein's surface, thereby protecting the trapped photons inside the pocket.

Energy sharing between various nested protein domains interacting with intermolecular adhesion of London forces at the nexus between phospholipids and the amphipathic proteins (e.g., myelin sheath reveals pathway relatively sealed at paranodes of 12 nm, (Cohen et al.,2020) has a key role in constraining the release of energy, resulting in *energy transformation* involving energy transitions[3] and energy transduction[4], and creating patterns of constrained energy connecting a vast array of lipophilic pathways in chains of membrane phospholipids within unsaturated fatty acids containing double carbon bonds in the hydrophobic regions (see Crawford et al., 2018**)**. Amphipathic proteins may act as the energy *'quantum boundary condition*' that constrains the release of free energy in a non-equilibrium process, channeling it into a limited number of degrees of freedom, causing more delayed entropy production (without assuming

[2] Biophotons are ultraweak photon emissions arising from spontaneous emission processes within biological systems. They are evanescent photons that are non-propagating or 'fleeting', and no assumption is given about 'photonic' waves (Bond, 2023).

[3] Energy transitions in π-conjugated systems, especially in long chains; when a localized EM wave interacts with the π-electrons, an electron absorbs a photon and moves to a higher energy state.

[4] Energy transduction is preferred over energy transformation as it includes internal energy.

entropy is negative) to initiate negentropic action where free energy is more stable and thus easier to amplify (Poznanski, 2024a).

Lipophilic pathways exist within and across membranes via *amphipathic* transmembrane proteins and through protein-protein interactions to adjacent neuronal lipophilic pathways. These interconnected routes along the neuronal membrane form a continuous pathway of delocalized π-electrons along fatty acid chains embedded in the bilayer (see **Fig. 1a**) in the presence of an intense electric field (Kitchener & Hales, 2020). In barrel-shaped membrane proteins, amphipathic strands are connected to neighboring strands through hydrogen bonds formed between the amide protons and the carbonyl groups of the polypeptide backbone. The cylindrical structure is stabilized by hydrogen bonding between the amino- and carboxy-terminal membrane-spanning strands (Kleinschmidt, 2015). Aliphatic amide bonds are formed through the elimination of a water molecule between two amino acids, contributing to the creation of hydrophobic pockets. Structurally similar amphipathic complexes are also found in non-mitochondrial systems, where they mediate interactions with both hydrophobic lipid bilayers and aqueous environments, highlighting the functional diversity of amphipathic complexes in neural tissue (see **Fig. 1b**).

Amino acids, such as tryptophan, phenylalanine, and tyrosine, contain aromatic amino acid residues that exhibit delocalized π-electrons in benzene ring molecules (Crawford et al., 2018). The delocalized electrons in benzene rings do have centripetal acceleration in their motion, which is described quantum mechanically. In delocalized orbitals, a nonbonding electron is a valence electron in an atom that does not participate in bonding with other atoms. The term refers to a non-bonding orbital in which the π-electron is delocalized throughout a molecule. The delocalization of π-electrons is termed π-electronic conjugation. Resonance structures are limited to conjugated π-bonds in all π-conjugated systems, and they are independent of light. The delocalized electrons oscillate between two possible positions. The three double bonds containing two electrons oscillate between these two states and have the same energy collected by resonating on the delocalized π-electrons. This energy transfer creates "electronic excitation-excitation" in the benzene moiety of aromatic amino acid residues in hydrophobic pathways.

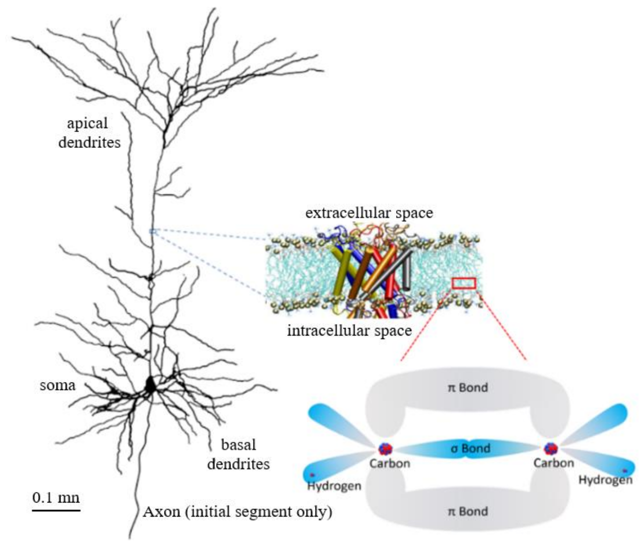


**Figure 1 (a)** *A schematic illustration of a pyramidal neuron showing an enlargement of the membrane composed of lipid structures such as arachidonic acids 2nm in length, interposed with ionic channel pores of 1-2 nm across the lipid bilayer 4nm in length. The arachidonic acid biomolecular structure is further enlarged, showing its subsection. The inset shows the double carbon-carbon bond molecular orbital configuration (R-CH=CH-R) where R = extension of this biomolecule. The double carbon bond consists of one π bond and one σ bond: Grey = π bond formed from p orbitals of each carbon (carbon typically has 3 sp2 orbitals and 1 p orbital perpendicular to the plane). The σ bond (blue) is due to the overlap between two sp2 orbitals. Hydrogen is bonded to carbon via σ bonds (sp2 hybridization). Source: Adapted from Georgiev (2021).*

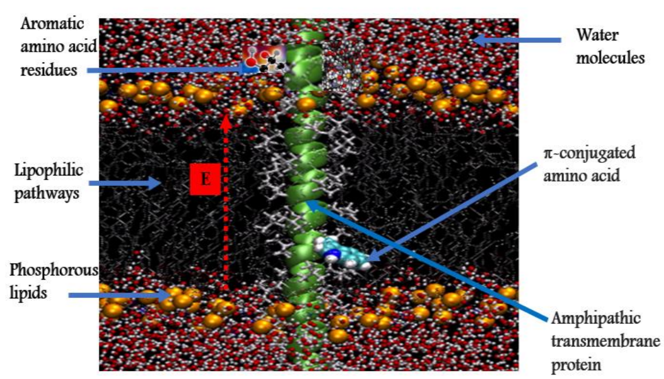


**Figure 1 (b)** *The idea of a cell membrane composed of lipid structures self-assembling in an aqueous environment encompasses a neuropil microcavity of aligned hydrophobic pockets across π-π stacking in π-conjugated moieties. Amphipathic membrane proteins comprise amino acids that self-assemble and are embedded or integrated into membrane lipids via London forces into the phospholipid's hydrophobic regions, forming amphipathic pathways. Source: Adapted from de Jesus & Allen (2013).*

The dipolar excitations comprise dipole-bound electron density distributions, determined from the solution of a Schrödinger-like wave equation first described for the bioplasma (a lipid-centric neuron model of brain functioning) by Pribram (1991). In Gould (1995), he compared the properties of the 'neural' wave equation and the Schrödinger equation. Its solution was derived by Poznanski et al. (2018, 2019). The system's total wave function ($\psi_n$) is a complex function. The actualization is based on phase differences of dipole-bound electrons as dipolar excitations guided by the quantum potential energy through the pilot-wave guiding principle (Fortin & Lombardi,2024). Although the process is quantum, the electronic excitations are represented in polarization waves or 'polarization wave functions'[5], which absorb the resonance energy accumulated in the π-electrons through quantum tunneling in hydrophobic pathways, including those across protein-protein interfaces. Polarization of the systems' total wave function reflects upon the sum of electric dipole moments, where the electric dipole moment measures the separation of positive and negative charges in the density of ionic bioplasma. In comparison, electron tunneling distances are facilitated through covalent bond hopping over distances of ~(2-3) nm, as shown in the mitochondrial membrane (cf., Stuchebrukhov, 2010). Still, it guides an ensemble of dipole-bound electron density distributions based on their phase differences. These instances are often found in proteins within the bioplasma, which carry many partially holistic[6] wave functions referred to as 'molecular' wave functions (Boeyens, 2000, 2008, 2010). The partially holistic nature of molecules represented in the system's total wave function ($\psi_n$) is associated with dipolar π excitations arising from π-electrons resonance, guiding the delocalized electron ensembles, and quasiparticles in the system are correlated through the system's total wave function, which encodes the quantum interactions between them. Therefore, the system's total wave function ($\psi_n$) is not probabilistic but superdeterministic, and it is appropriate for describing dipolar excitations in molecules (Boeyens, 2010).

The functional loci involve two processes across the amphipathic membrane proteins, where thermo-quantum fluctuations are serially amplified in the hydrophobic regions of membrane phospholipids far from thermal equilibrium. Thermo-quantum fluctuations in electronically excited states—arising from phonon-mediated transitions and manifested as stochastic variations in energy levels and transition rates—can be incorporated into the total wave function ($\psi_n$) of the system, which is dimensionless and describes the instantaneous state of the enveloping field density of molecular dipole-bound electrons with respect to their phase differences. (Poznanski et al., 2019, 2024).

Experiments have shown that biphoton entanglement interferes with anesthetics (Burdick et al., 2019), suggesting a quantum yield[7] of photons in neuroproteins (Patwa et al., 2024). General anesthetics bind directly to hydrophobic pockets in membrane proteins of neuronal membranes. Since anesthetics do not mix with water and affect hydrophobic regions (Hameroff, 2006), consciousness ceases to exist here. Hameroff does not provide a mechanism for the spontaneous return of consciousness after anesthesia. He suggests that aromatic amino acid units with π-resonance residues form dipoles through π-π stacking in nonpolar, hydrophobic regions of tubulin proteins. Anesthetics more commonly bind to amphipathic interfaces in membrane proteins, not tubulin (Dripps et al., 1988). Anesthetics disrupt these interactions by affecting London forces, which implies that the π-electron resonance of π-electron excitations is compromised. However, London forces do not directly impact π-π interactions; they may disrupt protein interfaces, undermining the functional unity of consciousness. Hameroff (2006, 2022) suggests that tubulin proteins (globular proteins) are the sites where consciousness originates.

The amphipathic transmembrane proteins can interact with enzymes, facilitating enzyme-substrate interactions, particularly in cases where hydrophobic pockets or membrane-bound environments are crucial for enzymatic function. These interactions help create the ideal conditions for enzymatic reactions at or near the membrane interface (Fairman et al., 2011). The entire neuronal membrane becomes a long-range proton tunneling pathway due to the continuous resonant energy supply along arachidonic acid chains in neuropil microcavities of amino acid residues where

[5] A "polarization wave function" is where electric polarization varies in space and time, often induced or driven by an external EM field.

[6] Partially holistic molecules are sectors of molecules guided by a negentropically derived quantum potential that gives form to the polarization wave function, and its quantum kinetic energy decays exponentially with distance.

[7] Quantum yield is the ratio of the number of photons emitted to the number of photons absorbed.

electrostatic interactions and intrinsic quantum effects link protein dynamics to enzyme catalysis (Klinman & Kohen, 2013). If anesthetics affect proton transfer or the electrostatic interactions between amino acids that facilitate this transfer, they could disrupt the protein's ability to function properly in ways that are not solely related to the conformational "shape" change of the protein itself. This could affect the signaling pathways and lead to the observed anesthetic effects. The anesthetic effect might involve a conformational "shape" change and the breakdown of specific proton-mediated interactions in proteins (Barchfeld & Deamer, 1985), which could contribute to the loss of function needed for conscious experience. In other words, anesthetics do not induce a leak in protons. Instead, the anesthetics produce a more general defect that allows protons and potassium ions to pass, increasing proton permeability.

Quantum biology encompasses quantum information biology (Asano et al., 2015), not including *quantum biological information*[8] through quantum memory, especially in terms of degrees of freedom forming information channels**.** For instance, nuclear protons align with the model of quantum brain dynamics; however, the model is too specific and cannot be applied to explain the intrinsic information, which is often overlooked in quantum biology (Madl & Renati, 2023). Information in the brain carries no semantic meaning, and its properties are influenced by de Broglie's 'hidden' thermodynamic energy. Yet, consciousness is partly entropic, and energy transformation that occurs through pathways with quantum degrees of freedom completes the process. Such pathways arise in hydrophobic microcavities formed by amphipathic membrane proteins, where quantum optical effects occur. Yet not all photon emissions are part of the quantum-optical effect in terms of contributing to the molecular biophysical mechanism of action in informational pathways. For example, adenosine triphosphate (ATP) is a nucleotide that is the primary energy source for cellular processes. Virtually all cellular processes result from dynamic interactions between proteins that act within protein complexes, pathways or networks of protein-protein interactions on a cellular or organismic level. They undergo protonation and emit photons in ATP fluorescence, but are not necessarily involved in consciousness.

[8] The definition of quantum biological information is similar in context to Messori (2019a); it has nothing to do with semantic information but relates to the intrinsic information attributed to energy transduction and negentropic gain. Therefore, there is no "thermodynamics of information" as information is not solely related to entropy, measured as increased uncertainty; it must also consider energy transduction. so it suggests that intrinsic information is, under a superdeterministic epistemology, more accurately described as epistemic quantum entropy — a measure of apparent information loss due to the complexity and inaccessibility of the hidden variables that fully determine the system's evolution.

## 3. Proton dynamics in neuropil microcavities

In quantum chemistry, a wave function describes the quantum state of a molecule. The wave function is dimensionless and describes the instantaneous state of the enveloping field of molecular dipole-bound electrons and protons (ions). Dipolar excitations are also associated with the system's total wave functions induced by the atoms and electrons that make up the molecule, often written as a product of an electronic wave function and a nuclear wave function, although in practice, approximations such as the Born-Oppenheimer approximation (which treats the nuclei as stationary relative to the electrons). The electronic wave function describes the distribution of electrons around the nuclei, while the nuclear wave function accounts for the positions of the nuclei themselves. The bioplasma is a lipid-centric model of brain functioning (Cavaglia et al., 2025), which was first proposed by Pribram (1991) to describe the coupling between the electronic wave function and nuclear wave function through electric charge. In this way, the charge of the molecule affects the wave function, influencing the electron distribution and interactions associated with protons ($H^+$), which results in quantum proton delocalization enabled by dipolar excitations (delocalized electron assemblies). The dipolar excitations of the ordered water molecules within the bioplasma of cortical neurons revolve around a time-dependent Schrödinger-like equation, which includes both quantum kinetic energy and quantum potential energy (Poznanski et al., 2024). This transduction of quantum potential energy occurs in individual sectors of molecules, which possess information potentials, without requiring nonlocal interactions (cf. Fortin & Lombardi, 2024).

The quantum potential emerges as a manifestation of the dynamical geometry (Hiley & Dennis, 2024; Hiley, 2011). It reveals novel 'directions' or 'pathways' in phase space (since quantum potential appears here) within the information-spacetime fabric (Fiscaletti, 2012), which do not exist classically and become apparent only when quantum effects are strong. It is a medium whose behavior is fundamentally quantum, where quantum correlations underlie it through its quantum fluctuations, providing macroscale stability through spatial correlations between the microscale, particularly in the context of the idea that functional spacetime geometry in the brain differs from physical spacetime geometry (Pribram, 2004). The quantum potential plays a crucial role in how π-electrons in a molecule interact and become entangled through the dynamics of their wave functions. Therefore, when quantum coherence is lost (due to decoherence**),** the quantum potential will no longer function as the guiding force for entanglement, and the system will begin to behave classically within the quantum realm.

Quantum proton delocalization in the hydrogen-bond networks is one example of how this works in enzymatic catalysis (Wang et al., 2014). In the context of interfacial, water is important because it can facilitate proton transfer via the quantum Grotthuss mechanism (proton tunneling) is modulated by hydrogen bond mediated collective vibrations—phonons are essential to proton dynamics in interfacial water, since water molecules can form structured hydrogen-bonded networks, allowing protons to tunnel through energy barriers between water molecules, allowing for much faster and more efficient proton transfer (Pusuluk et al., 2018). Hydrophobic surfaces (like oils), water tends to "repel" from the surface, as it does not form strong hydrogen bonds with the hydrophobic material, in this case, interfacial water can display hydrophobic characteristics, as the surface repels the water molecules, thus forming non-aqueous interfacial surface associated with *hydrogen bonding* that resembles the movement of ions through a solution, but within a non-aqueous environment (Messori, 2019b). The problem stems from a lack of hydrogen bonding in hydrophobic pockets in proteins since hydrophobic molecules cannot form hydrogen bonds with water molecules, but hydrophobic pockets in amphipathic membrane proteins and water wires (Vaitheeswaran et al., 2004) can indeed play a role in the delocalization of protons, forming hydrogen-bond networks as bridges within these hydrophobic pockets. In some situations, quantum proton delocalization stabilizes the deprotonation of an active site, and it is incorporated into hydrogen bond networks, giving rise to quantum proton delocalization.

Hydrated protons form their non-aqueous structures within hydrophobic spaces (e.g., protein pores within hydrophobic pathways or amphipathic complexes) via Grotthuss shuttling before migrating through them, as described in Peng et al. (2015). Hydrated excess protons are charge defects ($H^+$) deprotonated from peripheral amino acid residues (hydrophilic regions). Hydrophobic cavities near the peripheral amino acid residues serve as a medium for excess protons to form their aqueous pathways in a non-aqueous environment composed of individual hydrogen bond chains. In the wetting process, water molecules pass through the charge defect, and the hydrophobic pockets become aqueous, relying on a delocalized electronic charge defect ($H_3O^+$), which forms a bridge for proton transfer between hydrophobic pockets by donating protons to other molecules, such as protonation of amino acids, which alters their chemical behavior. Under anesthesia, the β-barrel proteins could have their hydrophobic pockets blocked, disrupting the bridges established by hydronium cations ($H_3O^+$). It should be noted that π-conjugated amino acids contain amines and carboxylates that can transport non-hydrated protons. It is suggested that these non-aqueous structures, located between hydrophobic regions, are utilized for energy transduction, resulting in fluctuations influenced by π-electron delocalization (see Sobczyk et al., 2005). The electron-rich nature of the π-conjugated system can stabilize the protonated or deprotonated forms of the molecule, making it crucial in processes such as enzyme catalysis or the binding of ions.

In confined hydrophobic environments, proton motion is quantum rather than thermal, unlike in bulk water. However, the system is not interacting with an external EM field in the polarization wave function (see Poznanski et al., 2024), which would require the inclusion of a time-dependent interaction term in the effective version of the Schrödinger-like equation, as suggested by Erol (2019). In quasiparticle-mediated proton dynamics, Meijer et al. (2021) derived an equation in the presence of an EM field where dipolar excitations modulate proton motion through an effective (epistemic) quantum entropy. The proton motion in phase space is governed by the 'action' function (Meijer et al., 2021):

$$\partial \nabla S/\partial t + (1/2m)\, \nabla.(\nabla S - q\mathbf{A})^2 + q\nabla\phi \qquad (1)$$

$$+ \mathbf{V}(t)m\, \partial\nabla \ln(\rho)/\partial t + \nabla(Q_{sq} + U) = 0$$

where S(x,t) is the 'action' function that has the dimension of [energy][time], t is time [time], m is the effective mass of protons [mass], ϕ is the electric potential in [mass][length]$^2$/([ampere][time]$^3$), **A** is the quantum mechanical vector potential that underlies the determination of the orbital velocity in [mass][length]/([ampere][time]$^2$), **V** is the kinematic viscosity of the water medium in [length]$^2$/[time], ρ is the current density of protons normalized by dividing by a characteristic value or reference current density involving interactions with other dipolar excitations (dimensionless), q is the electron charge in [ampere][time], $\nabla^2$ is the Laplacian in [length]$^{-2}$, U is the classical potential energy [energy], and the negentropically-derived internal energy ( $Q_{sq}$ ) in [energy] (Sbitnev, 2008):

$$Q_{sq} = -\frac{\gamma^2}{2\mathrm{m}}[\nabla \mathrm{S_Q}]^2 + \frac{\gamma^2}{2\mathrm{m}}\nabla^2 \mathrm{S_Q} \;\; = \;\; Q_k + Q_p \tag{2}$$

where $\gamma$ is the action parameter carries dimensions of [energy] [time]. The first term on the RHS of Eqn. (2) is viewed as the quantum kinetic energy ($Q_k$), and the second term on the RHS as the quantum potential energy ($Q_p$). The quantum kinetic energy ($Q_k$) occurs when delocalization occurs far from the dipolar core or nuclei, where the Coulombic attraction force becomes negligible, and pilot wave forces prevail. This signifies a negative $Q_k$ that carries a 'repulsive force' (or negentropic force) through internal energy transduction from $Q_p$ to $Q_k$, but does not separate the interacting atoms in molecules, unlike the Pauli repulsion force, which is negligible.

We define epistemic quantum entropy as a measure of apparent uncertainty arising from incomplete knowledge of a deterministic quantum system's hidden variables, consistent with a measure of the amount of hidden information in a system that arises due to an observer's limitations (Fagerholm et al., 2023). The middle terms in Eqn. (2) describe a sum of two quantum 'correctors' linked with the epistemic quantum entropy (dimensionless) (cf., Sbitnev, 2008; Fiscaletti,2012):

$$S_Q = -\tfrac{1}{2}\ln(\rho) > 0, \text{ since } 0 < \rho < 1 \tag{3}$$

The evolution of such a heuristic entropy-like measure in the context of superdeterminism reflects the increasing complexity of hidden variables that capture the system's apparent uncertainty (or randomness). This apparent uncertainty is based on observable distributions because it reflects our limited access to the hidden variables that govern the system's evolution, unlike inherent randomness, which does not exist in superdeterminism, such as fundamental entropy from the full quantum, e.g., von Neumann entropy. The system is deterministic and not probabilistic, as in Madelung's quantum mechanics (see Tsekov, 2012; Vervoort & Gingras, 2016).

We define $Q_{sq}$ as thermal motion in quantum-delocalized information systems, where the motion differs from Brownian motion because of entropic pilot waves. According to Heifetz & Cohen (2015), the fluctuation from the mean is represented by the imaginary part of the momentum ($\nabla S$). Therefore, in terms of the negentropically-derived internal energy ($Q_{sq}$). It can be positive or negative in amplitude, depending on how the internal energy is redistributed between the $Q_k$ (negative values) and $Q_p$ (positive values). When the momentum is zero, the $Q_k$ is negative, the $Q_p$ can be interpreted as an effective form of $Q_k$ and this, in turn, is influenced by temperature upon incorporating entropy in a non-equilibrium thermodynamic pilot wave theory. When this framework is applied, entropic pilot waves act as active agents, guiding coherent dynamics by channeling information across entropy gradients. Importantly, $Q_k$ here does not represent stochastic Brownian motion but contributes to the informational degrees of freedom inherent to the delocalized quantum system. Under specific conditions, the $Q_p$ thus functions as an informational kinetic channel—mediated by the thermodynamic properties of the Madelung fluid—that connects quantum nonlocality to classical physicality.

The action function is deterministic (fully determined by entropic pilot waves), incorporating the thermo-quantum fluctuations of dipolar excitations and proton motion through the phase. The thermo-quantum fluctuations exert competing effects and become '*mixed*' as thermal and quantum fluctuations. This can be observed with the temperature dependence of the internal energy. We note that $\frac{\nabla \mathrm{E}}{\nabla S^*} = T$ (*Tsekov, personal communication*), where S* is the entropy in units of [energy]/Kelvin and $E = -\frac{\partial S}{\partial t}$ is the total energy. It is possible to find the internal energy as a function of *T*. First, we note that $\nabla \mathrm{S_Q} = \left(-\frac{1}{2k_B}\right)\nabla S^*$ and from Eqn (2), we have (Poznanski et al., 2022):

$$Q_{sq} = -\frac{\gamma^2}{8\mathrm{m}T^2k_B^2}[\nabla(\tfrac{\partial S}{\partial t})]^2 + \frac{\gamma^2}{4\mathrm{m}\mathrm{T}k_B}\nabla^2(\tfrac{\partial S}{\partial t}) \tag{4}$$

where T is the temperature in Kelvin, $k_B$ is Boltzmann's constant in units of [energy]/Kelvin. Note that the temperature-dependent quantum energy depends on the derivative over time of the 'action' function. The internal energy depends on the 'action' function and the temperature (T), thus representing a hybrid approach that transitions from micro to macro, such as stochastic quantum dynamics, rather than quantum statistical mechanics, as the quantum density matrix approach is not employed. However, pure deterministic fluid mechanics is compatible with the physics of probabilistic systems, and so $Q_{sq}$ can be defined to result from the pressure gradient force from other quasiparticles that constitute the Madelung fluid (Vervoort & Gingras, 2016).

The internal energy dependence on temperature and the rate of change of phase difference (i.e., the variations in the action function (S) or its temporal derivative of the 'action' function) as fluctuations $(f)$ gives the following definition (Poznanski et al., 2022; Alemdar, 2023):

$$Q_{sq} = -\frac{\gamma^2}{8\mathrm{m}T^2k_B^2}[\nabla f]^2 + \frac{\gamma^2}{4\mathrm{m}\mathrm{T}k_B}\nabla^2(f) \qquad (5)$$

where $f$ is thermo-quantum fluctuation in units of [energy], γ is the 'action' function parameter in units of [energy][time], t is time [time], m is the effective mass of protons in units of [mass], $\nabla$ is the gradient in units of [length]$^{-1}$, and $\nabla^2$ is the Laplacian in units of [length]$^{-2}$. We have followed Dennis et al. (2015) in calling the $Q_p$ with the addition of the $Q_k$ as internal energy (Hiley,2002), where 'active' information contributes to redistributing the internal energy shared between the kinetic and potential parts, given that the underlying quantum influences at the molecular scale impact the fundamental brain dynamics, we dispense with a quantum ontological formalism based on the Bohmian quantum potential and replace it with 'concealed' motion through quantum degrees of freedom (Holland, 2015). In other words, we extend Bohmian mechanics to include non-equilibrium thermodynamics, where the energy in the $Q_p$ becomes temperature-dependent and is hidden thermodynamic energy guided by entropic pilot waves. In the quantum hydrodynamic picture, *entanglement* can be described in terms of spatial correlations of quantum fluctuations (Tsekov, 2012; Vervoort & Gingras, 2016; Alemdar et al., 2023).

## 4. Emergence of tripartite light-matter-vibration quasipolaritons

Quasipolaritons are a specific type of quasiparticles (photon-matter hybrid quasiparticles that combine photon and matter-like characteristics involving a conjugated system of π-electrons that become moderately coupled with photons) and collective vibrations within interfacial water cavities (or soft phonon modes from hydrogen bonding). Quasipolaritons are a broader concept than phonon-polaritons and are not 'dressed' polaritons often discussed in the context of strong coupling. They are multimode hybrid quasiparticles, not photon quasiparticles. The latter represent the collective excitations of photons within a medium or under strong coupling between photons and matter, often found in contexts like polariton formation, where photons strongly couple to electrons in a medium (see Ribereiro et al., 2019, for a review).

What empirical evidence supports the existence of quasipolaritons in biological systems? Quasipolaritons are tripartite hybrid quasiparticles guided by their polarization wave component, which is induced by π-electronic conjugation and does not require strong coupling. Instead, they require dipolar excitations, enhancing photoprotection in neuroprotein architectures through π-H interactions. One way to protect photons from excessive scattering or absorption is by guiding quasipolaritons along protein pores in interfacial water. They could serve as a suitable substrate for quasipolaritons that result from a phonon-dipole-proton-photon hybrid state. The quantum collective dynamics associated with dipolar excitations induced or driven by localized EM waves in aromatic rings influence the quantum yield (i.e., the ratio of photons absorbed to those emitted). It reflects the quantum collective dynamics in protein cavities encased by interfacial water, supported by delocalized vibrational excitations and ion-dipole interactions, such as those through π-H interactions, which enhance polarization within the protein pore. This supports the view of tripartite light-matter-vibration quasipolaritons through protein pores. Consequently, cavities within protein pores protect quasipolaritons from excessive loss due to scattering or absorption, thereby conserving their energy and reducing their interaction with thermal noise (i.e., unwanted energy dissipation mechanisms resulting from temperature). The crystal-like nature of interfacial water affects interactions with photons themselves, making the environment less susceptible to thermal noise, as the quasipolariton has a kinetic energy approximately $10^{-5}$ times smaller than thermal noise in neurons (Matsuura & Wasaki, 2014).

The striking ability of aromatic amino acids to self-assemble suggests that aromatic residues play a crucial role in forming π-H interactions, which are predominantly non-covalent interactions, including hydrogen bonding, π-π stacking, van der Waals forces, and electrostatic interactions. This electrostatic π-H interaction creates a favorable environment for energy transfer, thereby increasing the efficiency of energy exchange and enhancing photon emission. Proton transport in interfacial water, which is 'ordered' at protein surfaces, is partly in the normal liquid state (Pollack, 2015). Its molecular structure closely resembles that of condensed water ice (Pusuluk et al., 2019). Still, it is not typically classified as a condensed state like solid water (ice). The negatively charged nature of interfacial water (Pollack, 2013) and the positive charge of $H^+$ ions significantly enhance the coupling between electronic modes (from aromatic π-electrons) and protonic modes (from $H^+$ ions). The interfacial water is not completely ordered, i.e., its entropy is not zero; however, the rate of entropy loss is potentiated (Karplus & Faeman, 1994), suggesting that negentropic forces are at play (Poznanski et al., 2024). It should also be mentioned that since the condensed state of water is not a perfect crystal in solid water (or ice) to support quantized phonon excitations, both in acoustic and optical phonon modes, we ignore phonon oscillations (e.g., Nishiyama et al., 2024a). However, it does support delocalized vibrational excitations, especially in the hydrogen bond network—which are highly relevant to proton dynamics, energy transfer, and quasipolariton formation.

Hydrophobic pockets inside integral membrane protein pores contain a narrow zone of positively charged hydrogen ions ($H^+$), which can move in water and induce fluctuations in the orientation of surrounding water molecules. Such fluctuations alter the dipole moment of water molecules surrounding the protons as they move, causing fluctuations in the local electric field and releasing energy in the form of photons. This phenomenon resembles how polar molecules emit photons when they relax from an excited state. If excess energy is released from dipolar excitations in close proximity to aromatic rings, it can manifest as emitted photons. This phenomenon is more commonly associated with systems that undergo radiative transitions, contributing to the complexity of biochemistry and quantum biophysics in water (Mobley, 1994). The bioenergetics of proton transfer in hydrophobic cavities within protein pores must be continuous if quasipolaritons are to exist. In proteins, proton transport is not continuous (Cukierman, 2003), yet in π-electronic conjugation within hydrophobic cavities, there is a continuous proton transfer mechanism. Therefore, the coupling of proton motion to π-electron resonances via π-H interactions is pivotal in explaining how quasipolaritons come to exist. Microtubules do not employ this mechanism, as π-electron delocalization inhibits the intramolecular proton transfer process in polymers (Tarkka & Jenekhe, 1996). The hydrated excess protons contribute to the polarization wave component of the quasipolaritons. However, hydrogen bond contributions stabilize the quasipolariton in resonant cavities and peptides, which also occur in hydrophobic regions (Ragvander et al., 2009). The result is a microcavity quasipolariton whose macroscopic properties are dominated by quantum interactions, rather than through superradiance (Jibu et al., 1994; Nishiyama et al., 2024b; Babcock et al., 2024).

A quasipolariton is subject to decoherence or dissipative effects that weaken the coupling between the dipolar and photonic components. The polarization wave component of the quasipolariton is not free De Broglie waves but quasipolariton 'wave packets' transporting energy at different frequencies. The quasipolariton wave packets transport energy from the interaction between proton motion and delocalized polarization waves (Demchenko, 2023). Different extents of π-electronic conjugation can be achieved in a single molecule, modulating proton transfer (Demchenko, 2023). The spontaneous emission of photons accompanies protonic transfer due to the absorption-emission processes of fluorescent proteins (Shi et al., 2017). Protons in motion in cavities do not emit photons; only upon π-H interactions with delocalized polarization waves, combined to form dipolar excitations, is photon emission probable. Quantum proton delocalization interacts with π-electrons in aromatic rings to produce a quasipolariton. This occurs because localized EM waves in delocalized π-electrons emit photons. The effect of protons interacting with π-electron dynamics under quantum delocalization, known as dipolar excitations, results in quantum collective dynamics. Delocalized π-electrons form excited states when they absorb energy from π-H interactions (as well as through phonon-mediated interactions) and release energy in terms of photons emitted upon return to a lower energy state. Hence, the energy states of π-electrons (arising from their delocalized nature in amino acids) are excited through π-H interactions.

The quasiparticle is foundational; anything lesser is not biological or physiological and, therefore, irrelevant to consciousness as a biological phenomenon. This is often overlooked when applying quantum mechanics to biological processes. The quasipolariton has a core (quasiparticle) encased by protonic elements. So, *in vivo*, the core of the quasipolariton is inferred only by the outer shell of protons in enzymatic site structures, like hydrophobic pockets containing hydrogen-bonded networks, or between specific residues in the protein that facilitates proton transfer through polar regions within hydrophobic proteins folds (Peng et al., 2015) but not in aquaporins (Eisenberg, 2003). If the quasipolariton has a modular effect on cognition, causing conscious cognition through its outer shell of protons in motion, then consciousness can modulate the protonic environment, acting as a 'preparation' for conscious cognition to unfold, aided through proton motion in π-conjugated molecules. This understanding supports the idea that quantum-delocalized information pathways may hint at the existence of conscious cognition, which is referred to as phenomenal consciousness, as discussed by Baars (1993).

In some cases of π-π stacking, possible π-H interactions can occur when the hydrogen bonds are situated across the aromatic rings (see **Fig. 2**), and these π-H interactions through weak hydrogen bonds involve aromatic rings polarizing protons ($H^+$), modulating their motion by enhancing quantum yield. The π-H interaction can modulate protons as functional gates and not just passive relays. A crucial factor is that the coupling between the electronic and protonic modes is sufficiently strong to allow for effective energy transfer and spontaneous photon emission. Strong coupling here involves localized EM wave (not a traveling EM wave) passing through aromatic rings (e.g., benzene or other similar molecules) that emit photons. Aromatic rings are known for their conjugated π-electron systems, which can absorb and emit photons due to their electronic structure, specifically the delocalization of π-electrons. The coupling of the localized EM field to these rings could facilitate the creation of photon-emitting dipolar excitations, possibly leading to the spontaneous emission of photons. In the context of the quasipolariton, the localized EM wave could interact more effectively with the material (the aromatic rings in this case), leading to a stronger coupling between the localized photons and the resonant excitations formed in the π-electron system. Although the resonance between π-electrons is due to delocalization of π-electrons across the conjugated bonds, dipolar excitations can be influenced by proton ($H^+$) motion in microcavities above and across aromatic rings in electromagnetically induced dipolar excitations (Ciblis & Cosic, 1997; Sinkala, 2006). This is a crucial distinction because, unlike traveling EM waves, localized EM fields do not disperse, leading to a more intense interaction over shorter distances and potentially enhancing the coupling strength.

Traveling EM waves generate ionizing radiation not in the brain due to the low energy and localization of EM fields. EM fields generated through neural activity are localized and do not travel EM waves, producing nonionizing radiation. The generation of EM non-ionizing radiation is caused by electron transitions resulting from the absorption of photons, which leads to the emission of photons (EM radiation), but the process does not involve radiative transfer. So, the reference to EM radiation is exclusively for the traveling EM waves, which are absent in brains (Strupp,2024). Optical resonance can also occur in response to non-propagating EM fields, such as those confined within hydrophobic cavities or aromatic rings, with the resulting quantum yield being governed by the nature of light–matter interactions. Significant acceleration of electrons over large distances would be required for traveling EM waves since oscillations (or acceleration) of π-electrons in π-conjugated systems are typically localized to small sectors of molecules and do not produce large-scale coherent oscillations that could generate traveling EM waves. Hence, the EM radiation produced by dipolar excitations will likely be localized and involve energy transfer within molecules. The EM non-ionizing radiation resulting from metabolic activity in which ultraweak emission of biophotons is produced during neuronal communication is relatively well described (Erboz et al., 2025). Resonant energy transfer of localized π-electron oscillations plays a role in the energy transfer between amino acids in proteins. Yet, it is an insufficient mechanism for a synchronous energy transfer that could support consciousness in the brain. However, for longer interactions between proteins via protein-protein interfaces, there must be a way to couple π-electron oscillations across a larger-scale network of proteins via hydrophobic bridges between proteins to generate quasipolaritons. A speculative scenario is that proton motion, influenced by local EM from aromatic residues, could give rise to quantum coupling dynamics within π-rich regions of amphipathic membrane proteins. The crystal structure of interfacial water molecules isolates the photon state from decoherence for short periods (Pusuluk et al., 2019), forming a scaffolding for the quasipolariton (see **Fig. 2**). However, new pathways are present for quasipolaritons independent of water channels, i.e., originating from bulk water (Peng et al., 2015), in which proton transport in aromatic amino acid residues is mostly in non-aqueous environments. This suggests a unifying mechanism for the quasipolariton, like the role proposed by Moro et al. (2021), who suggested that photons can communicate among neurons.

According to philosophers, the fundamental ontology of consciousness is emergent physicalism and its unifying mechanism (Bayne & Chalmers, 2003). Our approach is not solely ionic; it incorporates electronic and ionic interactions. There are two sources of protons: 1. Water molecules at the interface of biomolecules, referred to as free protons; 2. Delocalized protons in hydrogen bonds within molecular proteins. Both free and delocalized protons work together to regulate the conditions necessary for consciousness unification. Free protons are highly unstable, while delocalized protons are stable. Interference between free protons and delocalized protons causes their destabilization, resulting in proton-induced proton transfer or protonation-induced proton transfer**.** Therefore, a greater concentration of free protons can quantum tunnel because their motion is coupled with delocalized electron motion via π-H interactions. This is not the classical Grotthuss mechanism. This is no longer proton tunnelling by itself, but proton tunnelling enabled by quantum electronic effects modulated by hydrogen bond-mediated vibrations—phonons are essential to proton dynamics in interfacial water.

In hydrogen-bonded networks, delocalized protons can modulate the electronic structure of adjacent π-conjugated systems by altering local electrostatic fields in enzymes (Wang et al., 2014). Conversely, the dynamic charge distribution of delocalized π-electrons can influence proton localization and mobility, creating a bidirectional coupling between charge and proton transport. This interplay is critical in processes such as proton-coupled electron transfer, which underlies key functions in energy conversion and biochemical signaling. Additionally, the pH of the local environment, which reflects proton activity, can modulate the behavior of ion channels and enzymes, thereby influencing signal transduction pathways. While spanning multiple scales, such two-way feedback is proposed to contribute to emergent properties in complex biological systems, potentially linking molecular-scale interactions to higher-order brain function.

The classical hopping of the protons (Peng, 2015) is aided by proton tunneling induced by the EM field and enhanced through π-H interactions. It occurs at an intermolecular distance of 2nm, ensuring greater delocalization. At the same time, a continuous resonant energy supply moves protons, during which the polarization wave component of the quasipolariton occurs when the momentum is zero. Negative $Q_k$ acti-

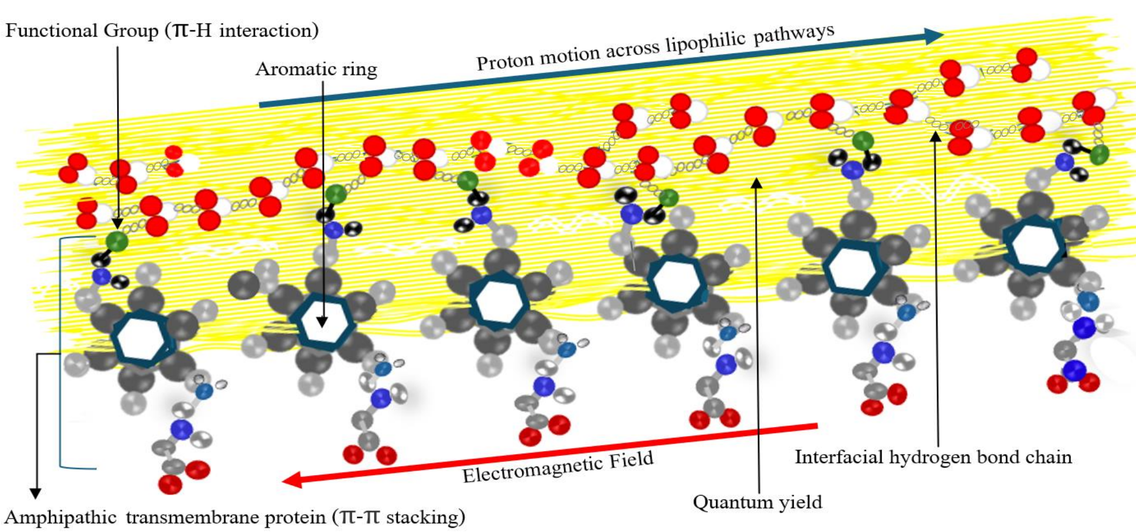


**Figure 2***: A schematic illustration of optical resonance within microcavity, aligned with π-conjugated systems exhibiting EM field–induced π–π stacking, contributes to intermediate coupling between confined photons and dipolar excitations in π-conjugated organic molecules. Anesthetics disrupt the coherent control of biochemical pathways in the neuropil, where cavities are found. Light-matter interactions involving vibrational modes stabilize the emergent dynamics of tripartite quasipolaritons. Delocalized π-electrons in aromatic rings within aromatic amino acids are further stabilized by functional groups across aromatic rings. Strong intramolecular H-bond across the aromatic rings resonates with protons from water molecules, facilitating resonant energy transfer along the hydrogen bond chain (interfacial hydrogen chain), a first shell of tightly bound water molecules. The π-H interactions are weak hydrogen bonds where a hydrogen atom interacts with a π-electron cloud of an aromatic ring. In contrast, classical hydrogen bonds can form between water molecules and the polar functional groups of aromatic amino acids (see green), which can form hydrogen bonds with water molecules but are not permanently bonded to water. The π-H interaction resonant energy is transferred between them, enhancing proton tunneling, which can be modulated by hydrogen bond-mediated vibrations since phonons are essential to proton dynamics in interfacial water. Modulation of electronic states in π-conjugated systems by proton motion and phonon coupling can facilitate resonant energy transfer, a process that involves resonance between energy levels without the emission of photons during the transfer. This process can potentially result in spontaneous photon emission when energy levels and molecular environments allow for efficient radiative relaxation.*

vates an anti-entropic process, such as ‘negentropic gain’, when the rate of change of epistemic quantum entropy is zero, signifying that the negentropic action acts as an informational pathway and enhances the proton tunnelling for information encoding. Therefore, the functional role of the quantum optical effect (Poznanski et al., 2024) is to produce quasipolaritons. The quantum optical effect is due to the quantum tunneling of protons across amphipathic membrane proteins embedded or integrated into hydrophobic regions along the phospholipid bilayer. It suggests that quasipolaritons and their mechanism of action— the quantum optical effect in aromatic amino acid residues within integral membrane proteins—are crucial for this phenomenon.

How can unstable quasipolaritons be stabilized? The resulting unstable quasipolaritons involve energy transfer through a delocalized system of π-electrons, protons, and electromagnetically induced photons. When the unstable quasipolariton wave loses its energy upon interaction with other molecules (e.g., water molecules) or relaxation to a lower energy state, it may release the excess energy in photons. This is called emission. When water molecules relax to lower energy states, they can emit photons; however, the interaction with light typically focuses more on absorption and scattering, which affect the transmittance of light, but it can also emit photons since modulation of the density of water molecules affects the transmittance of light (Nishiyama et al., 2024b).

This cooperative decay within an aqueous solution of coherent domains of interfacial water corresponds to EM mode (photons) (Del Giudice et al., 1988; Madl & Renati, 2023), resulting in a stable quasipolariton. Light-matter interactions involve vibrational modes that can stabilize the emergent dynamics of tripartite quasipolaritons by mitigating the effects of decoherence and external disturbances. The way these transitions happen—whether through cooperative excitations, energy gaps, or external driving by EM fields—can help enhance the stability and robustness of the system. These excitations often involve the collective transition of many particles to higher energy states and can be described by quasipolaritons through light-matter interactions involving vibrational modes within interface water cavities in protein pores; these quasipolaritons are protected from excessive loss due to scattering or absorption.

## 5. Quantum memory as an action selection mechanism

Consciousness is not a "thing" in the conventional sense—it is not composed of electrons, but emerges as a subjective and intrinsic process within a system (cf., Pockett, 2017). It arises from complex, dynamic interactions across multiple levels. Similarly, quasiparticles are intrinsic to physical systems, emerging from the collective behavior of their constituent components. They are not fundamental particles, but effective representations of collective excitations that help describe the system’s behavior. The properties of quasiparticles—such as energy, momentum, and lifetime—depend on the nature of the host system and are closely tied to its specific internal interactions. One particularly relevant example is the quasipolariton: a tripartite light-matter-vibration quasiparticle. This coupling enables quasipolaritons to carry information across multiple interaction domains, thus endowed with informational degrees of freedom, making them compelling candidates for modeling consciousness as a process. This idea is intriguing because consciousness is widely associated with information, yet the role of quasipolaritons in consciousness remains unproven. Establishing a meaningful connection would require articulating a plausible mechanism by which such quasipolaritons could participate in processes like action selection, possibly through a form of quantum memory in systems where information is quantum-delocalized across spatial or interaction domains.

The classical environment is in the quantum realm, manifesting through the thermodynamic behavior of the Madelung fluid, a compressible quantum medium whose pressure gradient force arises from fluctuations that shape movement, quantum coherence and energy transfer. Through its compressibility, the fluid transforms microscopic motion associated with $Q_k$ and delocalized, nonclassical degrees of freedom—into classical kinetic energy (Heifetz & Cohen, 2015), thereby facilitating a quantum-to-classical transition. Therefore, quantum entanglement comes through the compressibility of Madelung fluid. Such spatial correlations of the Madelung fluid, a compressible quantum medium whose pressure gradient force arises from fluctuations ($f$) that shape movement, quantum coherence and energy transfer (Roy, 2014; Marais et al., 2018). While plants utilize quantum coherence for energy transfer, microtubule neurons exhibit energy transfer and water properties that exhibit regions called coherence domains in quantum electrodynamics (Del Giudice et al., 1988). The information process in the brain relies on energy transduction occurring in widely distributed proteins that can represent dynamic information (Hameroff, 1987), but the key is under what conditions?

Information is not stored or processed in the brain; rather, information is agential—the performance of an action that produces an actionable force (information-based action). From this perspective, information arises from negentropic gain when internal energy transformation occurs under thermodynamic constraints in multiple informational pathways that are agentially connected to the complex EM fields generated by the brain. Quasipolaritonic modes of action can be a 'negentropic force', resulting in negentropic action, which requires the actualization of agency, often through a transition of patterns of energetic uncertainties to thermo-quantum fluctuations. The performance of negentropic action is agential, or 'shaping movement,' in new informational pathways yet to be actualized. The agential activity is the performance of a negentropic action influenced by quantum correctors of quantum potential energy, which are linked to entropic pilot waves (e.g., Fiscaletti, 2012) guiding internal energy toward more structured outcomes that we refer to as 'meanings.' These 'meanings' are composed of patterns of energetic uncertainties, and through negentropic action, which assigns 'meanings' from uncertainty in energy and reorganizes redundancies into energy transduction patterns of constrained energy.

In an agential context, these patterns of energetic uncertainties can be considered an "information structure" sculptured by the *actionable force* of the modality. In this context, information defines the modality (form) of energy transduction, emerging from energetic uncertainty and the pathways that create an 'informational structure' involving an action selection mechanism, a specific activity of intentionality (Searle,1991). Quasipolaritonic modes of action and movement that continuously select uncertainties in energy manifesting as intentionalities, allowing for the assignment of meanings independently of the environment. The relationship between 'intentions sensed as feelings' (Bohm, 1989) and the intentions-in-action (intentionalities) carries no privileged level due to the self-referential balancing of information process between levels, suggesting the relational ontology of information.

In the quantum realm of biological systems, internal energy consists of quantum potential energy, quantum kinetic energy, and their dynamic transformation into vibrational energy. This transformation requires time-dependent quantum evolution and does not occur during periods dominated by proton tunneling. As such, vibrational energy is a robust carrier of structured energy and intrinsic information — distinct from the information encoded through proton tunneling pathways. In microcavities, where quantum coherence is preserved, vibrational energy amplifies intrinsic quantum effects. However, during specific periods when the rate of quantum entropy change is zero, indicating steady-state evolution, vibrational coherence may decay or become thermally averaged, and proton tunneling becomes the primary carrier of information and coherence amplification.

It is essential to distinguish between intrinsic information and so-called biological information[9]. According to Miller et al. (2025): "*all biological information is uncertain because environmental signals can only reach cells by transmitting physical media such as interstitial spaces where they are subject to degradation*". These properties are absent from intrinsic information, which is based on an ontological conception of information, independent of sensory inputs. Additionally, it is distinct from cognitive information. Cognitive information[10] consists of symbols that convey meanings and represent mental or conceptual processes influenced by the environment.

In contrast, intrinsic information is non-contextual and non-representational. Therefore, it is misleading to conceptualize brain function in terms of information processing based on epistemological information. The information processing (IP) metaphor in brain functioning is misconstrued because intrinsic information does not exist epistemologically. Moving toward an ontological conception of information requires a dynamic information process (Liang et al., 2025).

Information is conveyed not by the energy variation of the signal itself, but rather by the energy transduction patterns of the signal. Therefore, the source of information selected through energy transduction occurs only when negentropic gain occurs, which acts

[9] Biological information refers to the patterns of energy transduction within living organisms that maintain low entropy. These patterns support functional complexity where apparent mixedness is closer to complexity, especially in superdeterministic frameworks. That means intrinsic mixedness, being probabilistic, does not apply here.

[10] Cognitive information involves processing symbolic representations that hold meaning. These symbols, language, thoughts, or abstract concepts are not directly tied to physical or biological processes but represent higher-order functions such as perception, reasoning, and communication. Cognitive information processing involves interpreting, storing, and manipulating these symbols, which goes beyond simple biological interactions to encompass mental phenomena.

as a trigger that can be associated with an action selection mechanism. The action selection mechanism entails selecting an action from among many possible actions. The proposed mechanism, selectionally advantageous instability (SAI), is closely related to the notion that information selection occurs due to a continuous yet rapid flux of functionality resulting from dynamic organicity (Poznanski, 2024). How are these functionalities formed in such a self-referential informational process? Edelman & Gally (2001) use of "degeneracy" effectively illustrates the spatial boundary conditions in an organism, including the brain. Degeneracy refers to the ability of different structural boundary conditions to perform the same function, also known as "functional redundancy." This is the structural approach of Tower (2024) regarding multiscale functional organization, where structural changes reflect self-assembly mediated by non-covalent interactions. These interactions involve complex EM fields generated by the brain and the breaking of covalent bonds, such as protein degradation due to protein folding instability. All biological molecules undergo the process of dynamic organicity (Schoenheimer, 1942). The confusion lies between 'functional redundancy, ' which reflects upon structural changes (cf., Tower, 2024), and 'informational redundancy' structures, which are embedded within the action landscape and remain functional due to their intentionality (Searle, 1983). When functions describe actions, they can be understood as 'decoded' information. This suggests that functions are descriptions of actions that can *be experienced* through decoded information. When the process is not self-referential, the minimum uncertainty cannot be decoded from the multiscale redundancy, and experience is not realized.

The *changing landscape of action*, which involves movement across scales where encoded information is decoded and subsequently encoded in higher processes as conscious cognition, refers to how precognitive brains utilize information in selection. This selection process relies on SAI invoked by delocalizing protons ($H^+$). The quantum delocalization of protons in hydrogen bond networks is extended (Wang et al., 2014), making the emergence of conscious cognition from π-H interactions conceivable through coupling dynamics of light-matter-vibration quasipolaritons and the complex neural dynamics associated with cognition, mediated by complex EM fields. The proton links the ionic and intrinsic quantum effects. Moreover, dipolar excitations are not sources of the $Q_p$ but are guided by it. In other words, quasipolaritons do not directly influence the $Q_p$. Therefore, the guiding entropic pilot waves exist without a causal feedback loop from the quasipolaritons, thereby creating a dynamic, self-referential information process through internal energy transduction and EM energy transduction via external sensory information as quantized EM waves (Erol, 2019). Local EM fields influence proton tunneling in hydrogen-bonded chains. Similarly, protons can amplify EM fields by trapping photons as quasiparticles. Repeating this creates a self-amplifying field-matter feedback loop**.** The brain is not just a system of neurons transmitting signals — it may be a field-sensitive, resonance-driven matrix where protons and EM waves co-regulate one another in a feedback cycle of amplification. Protons might be key players in amplifying weak EM signals that ultimately organize neural activity and produce higher-level cognitive functions. This is not just "bioelectricity" — it is the idea that quantum biochemistry produces usable localized EM waves, which can modulate and organize neural activity in subtle ways that electro-ionic models of action potentials *cannot explain*.

In interfacial water or "EZ water" (Pollack,2022), such as the water that exists at the surface of a solid (e.g., in contact with a hydrophilic surface) or at the boundary of two phases (like air and water), the behavior of hydrogen ions ($H^+$) can be different from that in bulk water. In bulk water, they are immediately hydrated to hydronium ions. $H^+$(aq) is the implied shortcut for hydrated proton, hydronium $H_3O^+$. Although it is commonly taught that the hydrated proton exists as the classical hydronium cation, $H_3O^+$ (Knight & Voth, 2012), it is more accurately described as a *delocalized electronic charge defect* spanning multiple molecules (Peng et al., 2015). The term "proton" is used ambiguously in chemistry to refer to both p and $H^+$. The hydrogen ion ($H^+$) and proton (p or $p^+$) are synonymous in chemistry. A hydrogen ion is a positively charged molecule and is only about 1/64,000 of the radius of a hydrogen atom. Interfacial water exhibits unique properties due to its interaction with the surface and reduced coordination, resulting in fewer neighboring molecules than bulk water. In interfacial water, free hydrogen ions ($H^+$) can still form hydronium ions ($H_3O^+$), but due to the unique properties of the surface or interface, their behavior can be quite different from bulk water. In the interfacial region, water molecules are less structured than in the bulk, which affects the interaction of hydrogen ions (protons) with water molecules. The interfacial water structure is disrupted, which could alter how protons bond with water molecules. This could make protons ($H^+$) more mobile at the interface, possibly allowing for quicker proton transfer than in bulk water. They may be more mobile and potentially participate in more complex interactions, such as ion pairs or hydrogen bonding with surface groups. Their concentrations and behavior can vary depending on the surface properties. In certain cases, protons in interfacial water might not immediately form hydronium ions. They could even interact with the surface, making their behavior distinct from typical interactions in the bulk solution. This makes interfacial water a very interesting and complex environment for proton dynamics.

Proton tunneling enhanced by anti-entropic conditions and negative kinetic energy of dipolar excitations at zero momentum in π-H interactions within amino acid residues. Even though the system maintains a conserved epistemic quantum entropy level (zero entropy change over time), locally there could be a reduction in entropy due to the negative quantum kinetic energy or quantum effects in the quantum delocalized information systems imply anti-entropic conditions in a system, particularly when considering quantum effects like tunneling or coherence. This information system is intertwined through proton delocalization occurring through an informational pathway derived from the continuity equation when $\nabla S_e$=0 to be:

$$\frac{\partial S_Q}{\partial t} = 0 \tag{6}$$

where the momentum of the dipolar excitations, $\nabla S_e$ indicates that the quantum kinetic energy $\frac{1}{2m}(\nabla S_e)^2 - \frac{\gamma^2}{2m}(\nabla S_Q)^2$ is negative. Internal energy influences negentropic action through a pilot wave force, also known as a negentropic force. At negative $Q_k$, the rate of change of epistemic quantum entropy is zero, indicating that the negentropic action serves as an informational pathway and facilitates proton tunneling through $Q_k$ at specific periods. However, the earlier work of Poznanski et al. (2018, 2019) lumped negentropic action acted upon by internal energy without explicitly delineating whether it was due to $Q_p$or $Q_k$. Eqn (6) states that negentropic action = rate of change of epistemic quantum entropy is zero. In other words, the claim that entropy transfer provides a measure of information propagation (Newman et al., 2022) is false because the rate of change (transfer) of entropy is zero, which signifies 'negentropic gain.' Together, energy transduction defines information only in the presence of 'negentropic gain' when epistemic quantum entropy is conserved, which yields movement through new pathways in a non-integrated manner.

In warm, open environments, such as the brain, nonequilibrium quantum systems can operate in steady-state conditions (Poznanski & Brändas, 2020). These conditions can give rise to transient "negentropic pockets"—brief regions of lowered entropy that allow for the quantification and storage of information (Brandis, 2024). This suggests that quantum memory in the brain could exist in forms unlike those typically modeled by photon–three-level atom systems (see Cano et al., 2017). In such nonequilibrium systems, long-lived coherent quantum modes (such as polaritons) are unlikely to persist indefinitely. Instead, brief, *tripartite quasipolaritons* may arise in response to specific structural or energetic conditions, such as those in water-lipid microcavities. These transient modes could generate short-lived coherent states shaped by quantum thermodynamic constraints, potentially creating information-preserving pathways at the subcellular level. When such events occur across cortical networks, the process of information binding may enable selecting one action over others. This line of reasoning offers a novel framework for exploring the role of quantum biological memory in the action selection process.

The idea of quantum-delocalized information systems (under thermodynamic constraints involving epistemic quantum entropy, π-conjugated systems, hydrogen bond networks) interacting under the principle of least action. These effects are particularly relevant in ultrafast processes at the edge of the quantum and classical regimes occurring by light–matter interactions involving vibrational modes in hydrogen-bonded networks. In such systems, coupling between delocalized protons ($H^+$) and π-electrons can facilitate coherent energy transfer, leading to the emission of microcavity photons with a finite quantum yield. The quantum evolution of the system is governed by a phase amplitude ($A_{amp}$), described by the principle of least action:

$$A_{amp} = e^{i(S_{photon} + S_{proton} + S_{\pi} + S_{int})/\hbar} \tag{7}$$

where $\hbar$ is the reduced Planck's constant ([energy][time]), $S_{photon}$ is the action of the EM field in the microcavity photon mode([energy][time]), S= $S_{proton}$ is the action of proton motion in the hydrogen bond network, including tunnelling ([energy][time]), $S_{\pi}$ is the electronic action over delocalized π-systems ([energy][time]),$S_{int}$ represents the interactions among proton ($H^+$), π–electrons, and photon modes—including proton–π–electron coupling and dipole interactions with microcavity photons ([energy][time]). It is not explored if proton motion can drive electronic transitions between π-electrons, which requires an explicit interaction term. On the other hand, if the coupling is weak and adiabatic, then the proton model modulates the electronic band structure (Born-Oppenheimer approximation). It remains unexplored whether proton dynamics can directly induce electronic transitions in the π-system, which would require an explicit non-adiabatic interaction term. In the adiabatic limit with weak coupling, however, the proton motion may modulate the electronic band structure consistent with the Born–Oppenheimer approximation. This formulation encapsulates the dimensionless quantum amplitude for photon emission (or absorption) processes mediated by correlated proton–electron dynamics. The dominant contribution arises from the path(s) that render the total action stationary, in accordance with the principle of least action. The phase is the total action in the exponent of $A_{amp}$ that governs the interference and constructive/destructive contributions in the quantum system. It is the sum of multiple contributions (from photons, protons, π-electrons, and their interactions), so the net phase is a function of all those dynamics.

## 6. Conclusion

Most neuroscience models (e.g., global workspace theory, Baars, 1993) argue that consciousness arises when information is gathered, synchronized, and integrated across multiple brain regions. This requires complex network dynamics, long-range synchrony, or recursive feedback loops, often assuming the 'binding' of information and mistakenly equating the metacognitive approach to consciousness as conscious cognition or correlates of consciousness. What we have proposed is an alternative quantum architecture, wherein the substrate of consciousness lies in neuropil microcavities, shaped by a non-Euclidean functional geometry intrinsic to the brain's dynamic processes. These neuropil microcavities enable intermittent quasipolaritons to function in local negentropic pockets across the cortex, when epistemic quantum entropy is conserved, and can be considered a form of functional entropy. They hold structured, meaningful information locally, instead of needing to be integrated or 'binded' but rather what is required is amplification, i.e., boosting or broadcasting the already coherent local content to a higher functional level (e.g., cognition) that becomes more evident through the enhancement of proton ($H^+$) motion in hydrogen-bond networks, modulated by the quantum-delocalized information systems and their feedback, signifying a two-way process.

The proposed quantum-delocalized information system includes quantum proton delocalization, which is not limited to biphoton entanglement between π–π electrons in protein pathways. We combine quantum optical effects and entropic pilot wave theory to investigate light-matter interactions involving vibrational modes, with a focus on quantum-enhanced photoprotection in neuroproteins within the brain. This approach proposed that consciousness emerges from the 'quantum information biology' of a quantum-delocalized information system rooted in two foundational pillars of biological functioning: degeneracy/redundancy and selectionism. formed from the emergence of the quasipolariton and its subsequent selection action. This represents a further extension of the holonomic (holographic) theory of brain functioning, as developed by Pribram (1991) (see Almendar et al., 2023). It is based on the quantum dynamics resulting from the interaction of bioplasma in neurons, generating energetic patterns in phase space. Our model extends this approach by specifying proton ($H^+$) motion in interfacial 'ordered' water as a bridge to cognition, carrying intrinsic information based on quantum dynamics. The consequence of these events leads to an information process that utilizes an action selection mechanism to select pathways where quasipolaritons are interacting across the cortex in networks of interconnected proteins and neural networks, and photons become entangled. This is how to describe subjectivity as an emergent phenomenon, akin to a quasiparticle, that exists only within a specific dynamic brain state and collapses when probed objectively from the outside. Such quantum effects can be sustained long enough to impact cognition by enhancing proton dynamics.

What specific mechanisms enable intermittent quasipolaritons to contribute to consciousness in the brain? The theory posits that the classical environment is embedded in the quantum realm, allowing for the possibility of non-Euclidean and noncommutative space-time curvature that would functionally resemble a *holarchical modularity* in the brain (Poznanski, 2024b). This suggests that the information process can be described nonclassically, particularly at sub-neuronal or molecular scales. This idea suggests that a major part of the brain's functional geometry is not a fixed, passive stage, but may possess a noncommutative, active structure that guides certain physical processes, such as the movement of protons ($H^+$), in ways that challenge classical intuition. These quantum-guided motions could open new, previously unseen pathways for signaling and, through information channels, mirroring the nonclassical trajectories enabled by $Q_p$ derived from the wavefunction to be affected indirectly in nonclassical (non-Euclidean or noncommutative) geometry of spacetime and temperature in quantum-delocalized information systems. The noncommutative nature of spacetime would then allow for nonlocal, nonclassical pathways in the brain—routes that would not be possible within a purely classical framework.

When many coherent negentropic pockets are "on" simultaneously, a macroscopic field could emerge, amplifying a global signature of consciousness without requiring the actual content to be integrated. In other words, consciousness does not need 'binding' of information across cognitive networks but arises when coherent states are amplified. Consciousness is emergent from local order that is widespread across the cortex when congruent in time. Therefore, the sufficient condition for consciousness is not 'binding" of information but when *sufficient* cortical negentropic pockets are "on" (coherent) simultaneously to produce functional unity. The necessary condition for consciousness is its emergence from local intermittent conservation of epistemic quantum entropy and the transduction of energy when the $Q_k$ becomes significantly greater than the total energy of a system, it can be reinterpreted as an effective form of $Q_k$. Moreover, it serves as a bridge between information-based configuration space and physical spacetime. This is geometrically permitted if the underlying space is noncommutative or curved, enabling forms of motion that are classically forbidden, such as tunneling. These behaviors reflect a deeper structure of physical spacetime, in which geometry reshapes the landscape of possible motion, and spacetime can produce new informational pathways. $Q_p$ is a feature of the underlying noncommutative geometry, and the underlying information-spacetime structure gives rise to nonclassical motion (Hiley, 2011). More than a conventional energy term, the quantum potential encodes curvature—or *informational geometry*—that governs the evolution of physical systems. These new pathways give rise to intentionality, suggesting the potential for understanding, a pivotal element of what consciousness is.

Consciousness is not a computational artifact, but rather an information process that involves quantum delocalized information systems in a non-Euclidean space, representing the functional geometry of the brain. The selection of information, defined as energy transduction during epistemic quantum entropy conservation through a quantum-optical effect involving quasipolaritons, was proposed to enhance proton ($H^+$) motion, thereby boosting, or broadcasting, the already coherent local content to potentially elevate the functional state of cognitive processes. Therefore, an often-overlooked necessary condition for consciousness is that it exists within an independent physical reality, before cognition, which is relative in terms of cognitive access, not absolute. It emerges through an agential relationship between quantum dynamic processes and the brain's inherently non-Euclidean functional geometry. This condition highlights the interactive nature of consciousness, where it is shaped by both the brain and its embodied multiscale context.

**Acknowledgment**

We thank J. Holmgren, E. Alemdar, V.I. Sbitnev, A. Pereira, Jnr., J. Ali, and E. Brändas for their discussions and contributions that enhanced the paper. We also appreciate L.A. Cacha for the illustrations and A. H. Sarajan for technical support.

**Conflict of interest**

The authors declare no commercial or financial relationships that could create a conflict of interest.

**References**

Alemdar, E. Poznanski, R.R. Cacha, L.A., Leisman, G. & Brändas, E. J. (2023) New insights into holonomic brain theory: implications for active consciousness. *Journal of Multiscale Neuroscience* **2**, 159-168.

Asano,M., Basieva,I., Khrennikov, A., Ohya, M., Tanaka,Y. & Yamato, I. (2015) Quantum information biology: from information interpretation of quantum mechanics to applications in molecular biology and cognitive psychology. *Foundations of Physics* **45**, 1362-1378.

Baars, B.J. (1993) *A Cognitive Theory of Consciousness* Cambridge University Press, Cambridge.

Babcock, N.S., Montes-Cabrera, G., Oberhofer, K.E., Chergui, M., Celardo, G.L. & Kurian, P. (2024) Ultraviolet super-radiance from mega-networks of tryptophan in biological architectures. *Journal of Physical Chemistry* **B 128**, 4035-4046.

Barchfeld,G.L. & Deamer,D.W. (1985) The effect of general anesthetics on the proton and potassium permeabilities of liposomes. *Biochimica et Biophysica Acta* **819**, 161-169.

Bayne, T. & Chalmers, D. (2003). What is the unity of consciousness? In A. Cleeremans (Ed.), *The Unity of Consciousness: Binding, Integration, Dissociation*. Oxford: Oxford University Press.

Boeyens, J.C.A. (2000) Quantum potential chemistry. *South African Journal of Chemistry* **53**,49-72.

Boeyens, J.C.A. (2008) The holistic molecule. In, J.C.A. Boeyens and J.F. Ogilvie (eds) *Models, Mysteries and Magic of Molecules*. Springer. Dordrecht.

Boeyens,J.C.A. (2010) Emergent properties in Bohmian chemistry. In C.L. Betrand (ed). *Electrostatics: Theory & Applications*. Nova Science Publishers.

Bohm, D. (1989) Meaning and information. In, P. Pylkkanen The Search for Meaning-The New Spirit in Science and Philosophy. Crucible Books, Swindon, UK.

Bond, E. (2023) The contribution of coherence field theory to a model of consciousness: electric currents, EM fields, and EM radiation in the brain. *Frontiers in Human Neuroscience* **16**, 1020105.

Brändas, E.J. (2024) Cognitive paradoxes and brain design. *Journal of Multiscale Neuroscience* **3**, 36-52.

Burdick,R.K., Villabona-Monsalve,J.P, Mashour,G.A. & Goodson,T. (2019) Modern anesthetic ethers demonstrate quantum interactions with entangled photons. *Scientific Reports* **5**, 11351.

Cano, L., Lara-Bustillos, D., Hautefeuille, M. & Velazquez, V. (2017) Is there a quantum origin in the biological memory? *Journal of Physics: Conference Series* **839**, 012023.

Cavaglia,M., Deriu,M.A. & Tuszynski,J.A. (2025) Toward a holographic brain paradigm: a lipid-centric model of brain functioning. *Frontiers in Neuroscience* **17**,1302519

Ciblis,P. & Cosic,I. (1997)The possibility of soliton/exciton transfer in proteins. *Journal of Theoretical Biology*, **184**, 331-338.

Chalmers, D.J. (1995) Facing up to the problem of consciousness. *Journal of Consciousness Studies* **2**, 200-219.

Cohen, C.C.H., Popovic,M.A., Klooster, J. Weil,M-T Wiebke Möbius, W. et al. (2020) Saltatory conduction along myelinated axons involves a periaxonal nanocircuit. *Cell* **180,** 311-322.

Crawford, M.A. Thabet,M., Wang,Y., Broadhurst,C.L. & Schmidt,W.F. (2018) A theory on the role of π-electrons of docosahexaenoic acid in brain function. *Oilseeds & Fats Crops and Lipids*. EDP Sciences.

Cukierman,S. (2003) The transfer of protons in water wires inside proteins. *Frontiers in Bioscience* **8**, s1118-1139.

de Jesus, A.J. & Allen,T.W. (2013)The role of tryptophan side chains in membrane protein anchoring and hydrophobic mismatch. *Biochimica et Biophysica Acta (BBA) - Biomembranes.* **1828**, 864-876.

Del Giudice, E., Preparata,G. & Vitiello,G. (1988) Water as a free electric dipole laser. *Physical review Letters* **61**, 1085-1088.

Demchenko, A.P. (2023) Proton transfer reactions: From photochemistry to biochemistry and bioenergetics. *BBA Advances* **3**, 100085.

Dennis, G., de Gosson, M.A. & Hiley, B.J. (2015) Bohm's quantum potential as an internal energy. *Physics Letters* **A 379**, 1224-1227.

Dripps,R.D., Eckenhoff, R. & Vandam,L.D. (1988) *Introduction to Anesthesia: The Principles of Safe Practice*. Saunders, Philadelphia.

Edelman, G.M. (1979) Group selection and phasic reentrant signaling: a theory of higher brain function. In, F.O.Schmitt & F.G.Worden (eds.) The Neurosciences: Fourth Study Program. MIT Press, Cambridge, MA.

Edelman, G.M. & Gally, J.A. (2001) Degeneracy and complexity in biological systems. *Proceedings of the National Academy of Sciences (USA)* **98**, 13763- 13768.

Erboz,A., Kesekler,E., Gentili, P.L. et al. (2025) Electromagnetic radiation and biophoton emission in neuronal communication and neurodegenerative diseases. *Progress in Biophysics & Molecular Biology* **195**, 87-99.

Erol,M. (2019) Resolution of brain-based consciousness as a quantum information field. *BRAIN-Broad Research in AI & Neuroscience.* **10**, 41-60.

Eisenberg,B. (2003) Why can't protons move through water channels? *Biophysical Journal* **85**,3427-3428.

Fagerholm, E.D., Dezhina,Z., Moran,R.J., Turkheimer,F.E. & Leech,R.(2023) A primer on entropy in neuroscience. *Neuroscience & Biobehavioral Reviews* **145**, 105070.

Fairman, J.W., Noinaj.N. & Buchanan,S.K. (2011) The structural biology of β-barrel membrane proteins: a summary of recent reports. *Current Opinion in Structural Biology* **21**, 523-531.

Fiscaletti,D. (2012) The quantum entropy as an ultimate visiting card of the De Broglie-Bohm theory. *Ukrainian Journal of Physics* **57**,946-963.

Fisher, M.P. (2015) Quantum cognition: the possibility of processing with nuclear spins in the brain. *Annals of Physics* **362**, 593-602.

Fortin, S. & Lombardi,O. (2024) Bohmian mechanics for quantum chemistry. In, A. Oldofredi (ed) *Guiding Waves in Quantum Mechanics*. Oxford University Press, Oxford.

Gassab,L., Pusuluk,O., Cattaneo.M. & Müstecaphoğlu,O.E. (2025) Quantum models of consciousness from a quantum information science perspective. *Entropy* **27**,243.

Georgiev, D.D. (2004). Bose-Einstein condensation of tunneling photons in the brain cortex as a mechanism of conscious action. Cogprints prepint

Georgiev, D.D. (2021) Quantum information in neural systems. *Symmetry* **13**, 773.

Gould,L.I. (1995) Quantum dynamics and neural dynamics: analogies between the formalisms of Bohm ad Pribram. In, J. King, K.H. Pribram (eds). *Scale in Conscious Experience: Is the Brain Too Important To Be Left to Specialists to Study*? Lawrence Erlbaum, New Jersey.

Hameroff, S.R. (1987) *Ultimate Computing: Biomolecular Consciousness and Nanotechnology*. North-Holland, Amsterdam.

Hameroff, S. R. (2006) The entwined mysteries of anesthesia and consciousness: is there a common underlying mechanism? *Anesthesiology* **105**, 400–412.

Hameroff, S. R.(2021). 'Orch OR' is the most complete, and most easily falsifiable theory of consciousness. *Cognitive Neuroscience*, **12**, 74–76.

Hameroff, S. R. (2022) Consciousness, cognition and the neuronal cytoskeleton—a new paradigm needed in neuroscience. *Frontiers in Molecular Neuroscience* **15**, 869935.

Hameroff, S.R. & Penrose, R. (1996) Orchestrated reduction of quantum coherence in brain microtubules: A model for consciousness. *Mathematics and Computers in Simulation* 40, 453-480.

Hameroff, S.R. & Penrose, R. (2014). Consciousness in the universe: A review of the "Orch OR" theory. *Physics of Life Reviews*, **11**, 39–78.

Heifetz,E. & Cohen,E. (2015) Towards a thermo-hydrodynamic like description of Schrödinger equation via the Madelung formulation and Fisher information. *Foundations of Physics* **45**, 1514-1525.

Hiley, B.J. (2002) From the Heisenberg picture to Bohm: a new perspective on active information and its relation to Shannon information. In, A. Khrennikov (ed.) *Quantum Theory: Reconsideration of Foundations*. Växjö University Press, Sweden.

Hiley,B.J.(2011) Process, distinction, groupoids and Clifford algebras: an alternative view of the quantum formalism. *Lecture Notes in Physics* **813**, 705-750.

Hiley, B.J. & Dennis,G. (2024) de Broglie, general covariance and a geometric background to quantum mechanics. *Symmetry* **16**, 67.

Holland, P. (2015) Quantum potential energy as concealed motion. *Foundations of Physics* **45**, 134-141.

Horne,E.A., Diaz,P., Cimino,P.J., Jung,E. ,Xu,C. et al. (2021) A brain-penetrant microtubule-targeting agent that disrupts hallmarks of glioma tumorigenesis. *Neuro-Oncology Advances* **3**, 1–11.

Jibu, M. & Yasue, K. (1995) *Quantum Brain Dynamics and Consciousness*. John Benjamins, Amsterdam, Netherlands.

Jibu, M. Hagan,S., Hameroff, S.R., Pribram, K. & Yasue, K. (1994) Quantum optical coherence in cytoskeletal microtubules: implications for brain function. *Biosystems* **32**, 195-209.

Jibu M., Pribram K.H., & Yasue K. (1996) From conscious experience to memory storage and retrieval: The role of quantum brain dynamics and boson condensation of evanescent photons. *International Journal of Modern Physics B* **10**, 1735–1754.

Kalra, A.P., Benny, A., Travis, S.M., Zizzi, E.A., Morales-Sanchez, A. *et al.* (2023) Electronic energy migration in microtubules. *ACS Central Science* **9**, 352−361.

Karplus,P.A. & Faeman,C. (1994) Ordered water in macromolecular structure. *Current Opinion in structural Biology* **4**,770-776.

Kerskens,C.M. & Pérez,D.L. (2022) Experimental indications of non-classical brain functions. *Journal of Physics Communication* **6**,105001.

Kleinschmidt,J.H. (2015) Folding of $\beta$-barrel membrane proteins in lipid bilayers — Unassisted and assisted folding and insertion. *Biochimica et Biophysica Acta-Biomembranes* **1848**, 1927-1943.

Klinman,J.P. & Kohen,A. (2013) Hydrogen tunnelling links protein dynamics to enzyme catalysis. *Annual Review of Biochemistry* **82**, 471-496.

Knight,C. & Voth,G.A.(2012) The curious case of the hydrated proton. *Accounts of Chemical Research* **45**, 101-109.

Krishna , S., Choudhury ,A., Keough ,M.B., Seo ,K., Ni,L. *et al.* (2023) Glioblastoma remodelling of human neural circuits decreases survival. *Nature* **617**, 599-607.

Khan,S., Huang,Y., Timuçin,D., Bailey,S., Lee, S. *et al*. (2024) Microtubule-stabilizer epothilone B delays anesthetic-induced unconsciousness in rats. *ENeuro* **11**(8).

Kitchener, P.D. & Hales, C.G. (2022) What neuroscientists think, and don't think, about consciousness. *Frontiers in Human Neuroscience* **16**, 767612.

Liang,Z. Fan,L., Zhang,B., Shu,W., Li, D. et al. (2025) The changes in neural complexity and connectivity in thalamocortical and cortico-cortical systems after propofol-induced unconsciousness in different temporal scales. *NeuroImage* **311**, 121193.

Libet, B. (1999) Do we have free will? *Journal of Consciousness Studies* **6**, 47-57.

Manovitz, T., Li,S.H., Ebadi,S., Samajdar,R., Geim, A.A. et al .(2025) Quantum coarsening and collective dynamics on a programmable simulator. *Nature* **638**, 86-92.

Marais,A., Adams,B., Ringsmuth,A.K., Ferretti,M., Gruber, J.M et al. (2018) The future of quantum biology. *Journal of the Royal Society Interface* **15**, 20180640.

Matsuura, H. & Wasaki, K. (2014) Quantization of artificial neurons: quantum current, model of polariton on axon. *International Journal of Innovative Computing, Information and Control* **10**, 1121-1133.

Meijer, D. K.F., Jerman, I., Meikikh, A.V & Sbitnev,V.I.(2021) Biophysics of Consciousness: a scale-invariant acoustic information code of a superfluid quantum space guides the mental attribute. In, A. Bandyopadhyay and K.Ray (eds.), *Rhythmic Oscillations in Proteins to Human Cognition*. Studies in Rhythm Engineering, Springer. Springer Nature Singapore

Messori, C. (2019a) The super-coherent state of biological water. *Open Access Library Journal*. **6**,e5236.

Messori,C. (2019b) Deep into the water: exploring the hydro-electromagnetic and quantum-electrodynamic properties of interfacial water in living systems. *Open Access Library Journal*. **6**,e5435.

Miller Jr.,W.B., Baluška,F., Reber,A.S. & Slijepčević, P. (2025) Biological mechanisms contradict AI consciousness: The spaces between the notes. *Biosystems* **247**, 105387.

Mobley,C.D. (1994) *Light and Water: Radiative Transfer in Natural Waters*. Academic Press, San Diego.

Montupil,J. Cardone,P., Staquet,C. Bonhomme,A., Defresne,A., et al., (2023) The nature of consciousness in anaesthetics. *BJA Open* **8**, 100224.

Moro,C., Liebert,A., Hamilton,C. et al. (2022) The code of light: do neurons generate light to communicate and repair? *Neural Regeneration Research* **17**, 1251-1252.

Newman, E.L., Varley,T.E. , Parakkattu,V.B., Sherrill,S.P. & Beggs,J.M. (2022) Revealing the dynamics of neuronal information processing with multivariate information decomposition. *Entropy* **24**, 930.

Nishiyma,A., Tanaka,S. & Tuszynski,J.A (2024a) Non-equilibrium quantum brain dynamics: water coupled with phonons and photons. *Entropy* **26**, 981.

Nishiyama, A., Tanaka,S. & Tuszynski, J.A. (2024b) Quantum brain dynamics: Optical and acoustic super-radiance via a microtubule. *Foundations* **4**, 288-305.

Patwa,H., Babcock,N.S. & Kurian,P. (2024) Quantum-enhanced photoprotection in neuroprotein architectures emerges from collective light-matter interactions. *Frontiers in Physics* **12**,1387271.

Pesenson,M.M. & Schuster,H.G. (Eds.) (2013) *Multiscale Analysis and Nonlinear Dynamics: From Genes to the Brain*. Wiley-VCH, Weinheim.

Peng,Y., Swanson, J.M.J., Kang, S-G., Zhou, R. & Voth, G.A. (2015) Hydrated excess protons can create their own water wires. *Journal of Physical Chemistry* B **119**, 9212-9218.

Pockett,S. (2017) Consciousness is a thing, not a process. *Applied Sciences* **7**, 1248.

Pollack, G.H. (2013) *The Fourth Phase of Water*. Ebner & Sons Publishers, Seattle, WA.

Posner,J.B., Saper,C.B.,, Schiff,N.D. & Plum,F. (2007) *Plum and Posner's diagnosis of Stupor and Coma*. Oxford University Press, New York.

Poznanski,R.R. (2024a) The dynamic organicity theory of consciousness: how consciousness arises from the functionality of multiscale complexity in the material brain. *Journal of Multiscale Neuroscience* **3**, 68-87.

Poznanski, R.R. (2024b) Some necessary construct of consciousness as defined in the dynamic organicity theory. *Journal of Multiscale Neuroscience* **3**, 98-108.

Poznanski, R.R. & Alemdar,E. (2024) The 'hidden' structure of uncertainties unfolding through poststructural dynamics of the entropic brain. *Journal of Multiscale Neuroscience* **4**, 264-273.

Poznanski, R.R. & Brändas, E.J. (2020) Panexperiential materialism: A physical exploration of qualitativeness in the brain. *Advances in Quantum Chemistry* **82**, 301-367.

Poznanski, R.R., Alemdar, E., Cacha, L.A., Sbitnev, V.I. & Brändas, E.J. (2022) The activity of information in biomolecular systems: a fundamental explanation of holonomic brain theory. *Journal of Multiscale Neuroscience* **1**, 109-133.

Poznanski, R.R., Cacha, L.A., Latif, A.Z.A., Salleh, S.H., Ali, J.,Yupapin, P., Tuszynski, J.A. & Tengku, M.A. (2018) Spontaneous potentiality as formative cause of thermo-quantum consciousness. *Journal of Integrative Neuroscience* **17**, 371-385.

Poznanski,R.R., Cacha,L.A., Latif,A.Z.A., Salleh,S.H., AIi, J., Yupapin, P., Tuszynski, J.A., & Ariff,T.M. (2019) Molecular orbitals of delocalized electron clouds in neuronal domains. *BioSystems* **183**, 103982.

Poznanski, R.R., Ali, J., Iannella, N.L. & Sbnitnev, V.I. (2024) Consciousness: a quantum optical effect in fluorescent protein pathways. *Journal of Multiscale Neuroscience* **3**, 224-241.

Pribram, K.H. (1991) *Brain and Perception: Holonomy and Structure in Figural Processing.* Lawrence Erlbaum, New Jersey.

Pribram, K.H. (2004) Brain and mathematics. In, Globus,G.G., Pribram,K.H, Vitiello,G (eds.) *Brain & Being*. John Benjamins Publishers, Amsterdam.

Pribram, K. H., Lim, H., Poppen, R., & Bagshaw, M.(1966). Limbic lesions and the temporal structure of redundancy. *Journal of Comparative and Physiological Psychology* **61**, 368–373.

Pusuluk,O., Farrow,T., Deliduman,C. Burnett,K.& Vedral,V. (2018) Proton tunnelling in hydrogen bonds and its implications in an induced-fit model of enzyme catalysis. *Proceedings of the Royal Society* A**474**, 201800037.

Pusuluk,O., Farrow,T., Deliduman,C. & Vedral, V. (2019) Emergence of correlated proton tunneling in water ice. *Proceedings of the Royal Society* **A475**, 20180867.

Raghavender, U.S., Aravinda,S., Shamala, N., Kantharaju, Rai, R. & Balaram, P. (2009) Characterization of water wires inside hydrophobic tubular peptide structures. *Journal of American Chemistry Society* **131**, 15130-15132.

Ribeiro,R.F., Martinez-Martinez,L.A., Du,M., Campos-Gonzalez-Angulo,J. & Yuen-Zhou,J. (2018) Polariton chemistry: controlling molecular dynamics with optical cavities. *Chemical Science* **9**, 6325-6339.

Roy, S. (2014) Quantum effects in biological systems. In, J. Balakrishnan & B.V. Sreekantan (Eds.) *Nature's Longest Threads: New Frontiers in the Mathematics and Physics of Information Biology*. World Scientific Publishers, Singapore.

Sinkala,Z. (2006) Soliton/exciton transport in proteins. *Journal of Theoretical Biology* **241**, 919-927.

Sbitnev, V.I. (2008) Bohmian split of the Schrödinger equation onto two equations describing evolution of real functions. *Kvantovaya Magiya* **5**, 1101-1111.

Schoenheimer, R. (1942) *The Dynamic State of Body Constituents*, Harvard University Press, Cambridge, MA.

Searle, J.R. (1983) *Intentionality*. Cambridge University Press, New York.

Searle, J. R. (1991). Consciousness, unconsciousness and intentionality. *Philosophical Issues,* **1**, 45-66.

Shi,S., Kumar,P. & Lee, K-F. (2017) Generation of photonic entanglement in green fluorescent proteins. *Nature Communications* **8**, 1934.

Sizoo, E.M., Braam, L., Postma, T.J., Roeline,H., Pasman, W., Heimans, J.J. et al., (2010) Symptoms and problems in the end-of-life phase of high-grade glioma patients. *Neuro-Oncology* **12**, 1162–1166.

Sobczyk,L., Grabowski,S. & Krygowski,T.M. (2005) Interrelation between H-bond and Pi-electron delocalization. *Chemical Reviews* **105**, 3513-3560.

Strupp, W. (2024) A new variant of the electromagnetic field theory of consciousness: approaches to empirical confirmation. *Frontiers in Neurology* **15**, 1420676.

Stuchebrukhov. A. (2010) A long distance electron tunneling in proteins. *Laser Physics* **1**, 125-138.

Tarkka,R.M. & Jenekhe, S.A. (1996) Effects of electronic delocalization on intramolecular proton transfer. *Chemical Physics Letters* **260**, 533-538.

Tegmark. (2000) The importance of quantum decoherence in brain processes. *Physical Review* **A61**, 4194-4206.

Tower,J. (2024) Selectivity advantageous instability in biotic and pre-biotic systems and implications for evolution and aging *Frontiers in Aging* 5, 1376060.

Tsekov,R. (2012) Bohmian mechanics versus Madelung quantum hydrodynamics. Annual of the Sofia University St. Kliment Ohridski, Faculty of Physics, Bulgaria, Special Edition 112-119.

Vaitheeswaran, S., Yin, H., Rasaiah, J.C. & Hummer, G. (2004) Water clusters in nonpolar cavities. *Proceedings of the National Academy of Science (USA)* **101**, 17002-17005.

Vervoort,L. & Gingras,Y. (2016) Macroscopic oil droplets mimicking quantum behavior: How far can we push an analogy? *International Studies in the Philosophy of Science* **29**, 271-294.

Wang, L., Fried, S.D., Boxer, S.G. & Markland, T.E. (2014) Quantum delocalization of protons in the hydrogen-bond network of an enzyme active site. *Proceedings of the National Academy of Science (USA)* **111**, 18454-18459.