Oscillatory Continuity Across Physical and Cognitive Scales A Layered Assessment of Evidence and Hypothesis, from Vacuum Fluctuations to Social Coherence

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Abstract

Oscillation recurs as a structural motif at every scale of nature that has been examined in detail, from the zero-point fluctuations of the quantum vacuum to candidate wave-function descriptions of the universe as a whole. This paper assembles that recurrence into an explicit, ten-layer hierarchy — vacuum, particle, fermion, atom/molecule, cell/organism, population, cognition, language, society, cosmos — and, for each layer, separates what is experimentally established from what is a specific, named hypothesis that extends the established result beyond its tested domain. The lower layers (vacuum fluctuations, particles as field excitations, intrinsic fermionic oscillation, molecular vibration, biological rhythms, population cycles) rest on independently replicated physics, chemistry, and biology. The upper layers (phase coherence as a sufficient condition for consciousness, oscillatory structure in linguistic meaning, coherence-based coordination at societal scale) are stated here as explicit, falsifiable hypotheses, clearly distinguished from the evidence beneath them. The purpose of the exercise is not to claim that the whole stack is proven, but to make visible exactly where the evidentiary floor ends and the hypothesis begins — a distinction that is often blurred in cross-disciplinary "resonance" arguments, and that this paper deliberately keeps sharp.

1. Introduction

Physical theory keeps returning to the same object: a system whose state varies periodically around an equilibrium, characterized by a frequency, an amplitude, and — when more than one such system is present — a phase relationship to its neighbors. This object appears, with only superficial differences of notation, in the quantization of the electromagnetic field, in the intrinsic motion of a free Dirac particle, in the vibrational spectra of molecules, in the pacemaker dynamics of cardiac tissue, in predator–prey population cycles, and in formal treatments of the wave function of the universe itself. The recurrence is well documented within each discipline separately; what is attempted less often is an explicit, scale-by-scale audit of *how well established* each instance is, and whether the step from one scale to the next is a proven physical consequence or an imported assumption.

That audit is the purpose of this paper. Sections 2–11 proceed layer by layer, from the vacuum to the cosmos. Each section states the core claim, gives its experimental or mathematical grounding, and — where relevant — introduces a specific extension proposed in the literature, explicitly labeled by its evidentiary status. Section 12 discusses what the completed hierarchy does and does not establish, and what would be required to test its more speculative layers.

Two methodological commitments run through the paper. First, "established" is used only for claims that are experimentally verified or are direct, uncontested mathematical consequences of a well-tested theory. Second, when a named researcher's specific proposal is used to bridge two layers, that proposal is presented as one candidate mechanism among possible others, not as the layer's settled explanation — the strength of the *layer* is not inherited automatically by every hypothesis attached to it.

2. Layer 0 — The Vacuum Oscillates, Possibly All the Way Down

For every mode of a quantum field, the ground-state energy is $E_0 = \frac{1}{2}\hbar\omega$: the vacuum is not empty but is a floor of fluctuating field modes. This is not a theoretical artifact; it has a measurable footprint. The Casimir effect — a measurable attractive force between closely spaced conducting plates, arising because the plates restrict which vacuum modes can exist between them — and the Lamb shift — a small but precisely measured splitting in the hydrogen spectrum caused by the electron's interaction with vacuum fluctuations — are both established, repeatedly confirmed experimental signatures of this zero-point structure.

A separate and more open question is whether this oscillation is itself fundamental, or whether it emerges from a deeper, discrete substrate. Gerard 't Hooft's Cellular Automaton Interpretation (CAI) of quantum mechanics proposes that standard quantum mechanics is a statistical tool rather than a final ontology, and that a time-reversible, deterministic cellular automaton can be shown to obey the same evolution equation as a quantum state (’t Hooft, 2016). This is a minority position within physics, but it is mathematically developed by a Nobel laureate and has recently received a concrete computational test: van Berkel, de Graaf, and van Hee (2025) initialized a one-dimensional stochastic cellular automaton in the third eigenstate of the quantum harmonic oscillator and found that its deterministic evolution reproduces the theoretically predicted oscillation frequency to high accuracy, with no randomness or wave-function collapse invoked at any step.

Status. Zero-point energy and its Casimir/Lamb-shift signatures: **established**, independently and repeatedly confirmed. The CAI as the deeper substrate from which that oscillation emerges: **a minority but mathematically serious research programme**, now with direct computational support, but at present **empirically indistinguishable from standard quantum mechanics** — it reinterprets what oscillation fundamentally *is*, without yet producing a testable prediction that standard quantum mechanics does not also make.

3. Layer 1 — Particles as Field Excitations

In quantum field theory, a particle is a localized excitation of a field — the photon as an excitation of the electromagnetic field, the electron as an excitation of the electron field. This follows directly from Layer 0: if the vacuum is already an oscillating floor, particles are the discrete, countable peaks riding on top of it.

Status: established. This is the standard, experimentally confirmed formalism of quantum field theory.

4. Layer 2 — Fermions: Intrinsic Oscillation

Zitterbewegung — the intrinsic trembling motion of a free fermion — follows directly from the ordinary Dirac equation, as an interference effect between positive- and negative-energy solutions, first identified by Schrödinger in 1930. This gives, without any additional assumption, a second and independent source of oscillation: fermions are not only field excitations (Layer 1), they carry an intrinsic oscillatory frequency of their own.

A specific further development, relevant to this paper's aim of connecting layers, comes from Peter Rowlands' nilpotent dual-space formalism. In this framework, spin-½, Berry phase, and zitterbewegung arise together from defining a localized point particle simultaneously with the non-local vacuum structure that fixes its relation to the rest of the universe (Rowlands, 2017). This is the explicit ingredient that connects Layer 2 back to Layer 0: the fermion oscillates not in isolation, but because the vacuum itself is incorporated, as a dual structure, into the definition of the particle.

Status. Zitterbewegung itself: **established**, a direct and uncontroversial consequence of the Dirac equation. The specific vacuum-coupling account offered by Rowlands' dual-space formalism: **one published, mathematically self-consistent reformulation**, not the only way to derive zitterbewegung, but the most explicit bridge available in the literature between vacuum structure (Layer 0) and fermionic oscillation (Layer 2).

5. Layer 3 — Atoms and Molecules

Electron orbitals and molecular vibrations (infrared-active bonds) are oscillating systems built from the fermions and fields of the preceding layers, and are confirmed daily by infrared spectroscopy and nuclear magnetic resonance.

Status: established. Standard quantum chemistry.

6. Layer 4 — Cells and Biological Rhythms

Circadian clocks (molecular feedback loops) and heartbeat (sinoatrial pacemaker cells) are extensively characterized coupled biological oscillators. Neural oscillations are broadly measured and replicable with EEG, MEG, and local field potentials.

The specific mechanism most relevant to coupling across oscillators is Pascal Fries' Communication-through-Coherence (CTC) hypothesis: the proposal that phase coherence between oscillating groups of neurons is the mechanism that modulates effective communication between brain regions (Fries, 2015). CTC is the field's most widely used functional model for coupled neural oscillators, and it is precisely the kind of mechanism needed to move from isolated oscillators (Layer 3) to coupled, functional oscillator networks (Layer 4 and beyond).

Status. That neural oscillations exist and synchronize: **established**, broadly replicated. That coherence is itself the communication mechanism: a **well-supported, actively researched hypothesis** within neuroscience — the dominant functional model for coupled neural oscillation, but one with an acknowledged open debate about whether coherence is a cause of information transfer or a byproduct of shared input (see, e.g., discussions of cross-frequency coupling as an alternative or complementary mechanism).

7. Layer 5 — Populations

The Lotka–Volterra equations show that oscillation does not stop at the level of the individual organism but continues into interacting populations: predator–prey coupling as an oscillator at ecological scale. The Canadian lynx–snowshoe hare cycle, reconstructed from Hudson's Bay Company fur-trading records, is the classic empirical illustration.

Status. The mathematical model is **established**: coupled nonlinear equations of this form provably generate cycles. The **empirical fit is confirmed for a subset of real systems and variable for others** — a fair characterization is that oscillatory coupling demonstrably operates as a mechanism at this level, without every ecosystem matching the idealized model.

8. Layer 6 — Cognition and Consciousness

Here the argument shifts from "oscillators that are measured" to "oscillators proposed as an explanation for something not yet independently measurable." The specific claim introduced at this layer — that phase coherence between neural oscillations is not merely correlated with, but identical to, consciousness itself — goes further than what Fries' established coherence-functionality result (Layer 4) supports on its own.

Status: hypothesis. This is the point at which the hierarchy stops summarizing existing evidence and becomes a specific proposal, with Layer 4 as the strongest available foundation beneath it.

9. Layer 7 — Language and Meaning

Spoken language is, acoustically, a vibration; modern language-model embeddings no longer retain that acoustic information. Building on Layer 6: if consciousness is coherence, and language is an expression of consciousness, the further question is whether meaning itself carries an oscillatory structure that is lost when moving from sound to vector representation.

Status: hypothesis, and the weakest-supported step in the chain — there is no measured mechanism directly linking acoustic oscillation to semantic content. This is presented as a testable hypothesis, not an established link.

10. Layer 8 — Societies

Inter-brain synchrony between two conversation partners has been measured with hyperscanning EEG: Dumas, Nadel, Soussignan, Martinerie, and Garnero (2010) recorded simultaneous EEG from interacting dyads and demonstrated inter-brain synchronization associated with social interaction — an established extension of Layer 4/6 coupling to the two-person scale. The extrapolation to societies — coordination at population scale through the same coherence mechanism — is the step from two coupled brains to millions.

Status: the dyad scale is established; the societal scale is hypothesis. This is an honest way to state the boundary: a measured foundation at two people, and an unproven extrapolation at population scale. The underlying architecture — coherence as a coupling mechanism (Layer 4) — is at least the same principle that would need to be tested at larger scale, not a different one.

11. Layer 9 — Cosmos

The Wheeler–DeWitt equation closes the circle back to Layer 0. In specific minisuperspace models of quantum cosmology, the wave function of the universe takes an oscillating form: for a simple closed Friedmann–Robertson–Walker minisuperspace, the Wheeler–DeWitt equation reduces to the form of a dimensionless quantum-harmonic-oscillator equation, yielding equally spaced quantized levels for the volume of the (toy) universe. More elaborate treatments — for example, canonical transformations that map minisuperspace dynamics onto a two-dimensional hyperbolic-oscillator form — allow the equation to be solved explicitly, though the absence of an external time parameter in the Hamiltonian constraint means the resulting spectrum does not carry the same physical interpretation as ordinary harmonic-oscillator energy quantization.

Status: established that oscillating solutions exist within specific, chosen minisuperspace models; open whether this is the form our actual universe takes. What the hierarchy can fairly note is that the mathematical family resemblance to the quantum harmonic oscillator of Layer 0 is not a notational coincidence — the same equation form recurs at the smallest and largest scales considered here, even though its cosmological interpretation remains unsettled and operator-ordering ambiguities in the full theory are an acknowledged open problem in the field.

12. Discussion

Laid end to end, the hierarchy reads: a vacuum that oscillates, and may rest on a deeper deterministic substrate (established zero-point energy; hypothesis-level substrate) → oscillating field modes as particles (established) → fermions with intrinsic oscillation, coupled to vacuum structure (established zitterbewegung; one specific published coupling account) → atoms and molecules (established) → coupled biological oscillators with coherence as a candidate functional switch (established oscillation; well-supported but contested coherence hypothesis) → population cycles (established model, variable fit) → consciousness as coherence (hypothesis) → meaning as oscillation (weakest hypothesis) → social phase-coupling, established at dyad scale and hypothetical at societal scale → a cosmic wave equation with the same mathematical form as Layer 0 (established within model choice).

The pattern that remains after this audit is itself informative. From Layer 0 through Layer 5, each step rests on an independently published, experimentally or mathematically established result. From Layer 6 onward, the same underlying principle — coupled phase oscillators — is extended as an explanatory model into domains where it has not yet been directly measured. That is not a flaw to be hidden; it is the precise point at which a testable research programme begins, with Layers 0–5 forming the evidentiary floor it must remain answerable to.

Two implications follow for how this hierarchy should be used. First, claims at Layers 6–8 should be treated, and tested, as falsifiable hypotheses in their own right — for example, the coherence-consciousness link (Layer 6) predicts specific, checkable relationships between measured phase coherence and reportable conscious states, independent of whether Layers 0–5 are correct; a failure at Layer 6 would not indict the established physics beneath it, and a success at Layers 0–5 does not, by itself, provide evidence for Layer 6. Second, the recurrence of the same oscillator mathematics at very different scales (Layer 0 and Layer 9 in particular) is worth taking seriously as a structural observation, but structural resemblance in the equations is not by itself evidence of a shared physical mechanism across scales; that remains to be established independently at each boundary.

13. Conclusion

Oscillation is a genuinely recurring structural feature of nature, well documented from the quantum vacuum through molecular, biological, and ecological systems. This paper's contribution is not a new physical result but an explicit accounting: separating, layer by layer, what is established from what is proposed. The lower six layers of the hierarchy (vacuum through populations) stand on independently replicated evidence. The upper four (consciousness, language, society, cosmos-as-interpreted) contain specific, named hypotheses that extend the same oscillatory logic into domains where direct measurement is harder or, in the case of the deepest vacuum substrate and the cosmological wave function, not yet decisively available. Keeping that boundary visible — rather than letting the evidentiary weight of the lower layers bleed upward by association — is the condition under which the upper layers can be pursued as genuine, falsifiable research questions rather than as claims already carried by the physics beneath them.

References

Casimir, H. B. G. (1948). On the attraction between two perfectly conducting plates. *Proceedings of the Koninklijke Nederlandse Akademie van Wetenschappen*, 51, 793–795.

Dumas, G., Nadel, J., Soussignan, R., Martinerie, J., & Garnero, L. (2010). Inter-brain synchronization during social interaction. *PLoS ONE*, 5(8), e12166.

Fries, P. (2015). Rhythms for cognition: Communication through coherence. *Neuron*, 88(1), 220–235.

Lamb, W. E., & Retherford, R. C. (1947). Fine structure of the hydrogen atom by a microwave method. *Physical Review*, 72(3), 241–243.

Lotka, A. J. (1925). *Elements of Physical Biology*. Williams & Wilkins.

Rowlands, P. (2017). Nilpotent quantum mechanics: Analogs and applications. *Frontiers in ICT*, 4, 20.

Schrödinger, E. (1930). Über die kräftefreie Bewegung in der relativistischen Quantenmechanik. *Sitzungsberichte der Preussischen Akademie der Wissenschaften, Physikalisch-Mathematische Klasse*, 24, 418–428.

't Hooft, G. (2016). *The Cellular Automaton Interpretation of Quantum Mechanics*. Fundamental Theories of Physics, vol. 185. Springer.

van Berkel, K., de Graaf, J., & van Hee, K. (2025). Experiments with Schrödinger cellular automata. *Quantum*, 9, 1811.

Volterra, V. (1926). Variazioni e fluttuazioni del numero d'individui in specie animali conviventi. *Memorie della Reale Accademia Nazionale dei Lincei*, 2, 31–113.