

Exploring Rational Quantum Mechanics

Edited transcript of an exchange between Andy Ross and an AI assistant held on August 29, 2026

AR A new version of quantum mechanics, called rational quantum mechanics and championed by Oxford professor Tim Palmer, aims to replace continuous Hilbert space with a discrete version of Hilbert space. Palmer says this reproduces all the experimental results of QM but avoids the metaphysical baggage of superposition and entanglement. He claims to explain Bell test results without “weirdness” too, and says the only price is abandoning the classical continuum. All this is reported in this week’s *New Scientist*. Can you offer a more technical account of Palmer’s ideas, without going into the full formality of his published work?

AI Certainly! Tim Palmer’s proposed “rational quantum mechanics” is a novel interpretation and reformulation of quantum mechanics that aims to resolve deep conceptual puzzles by changing the mathematical foundation of the theory. Here’s a more technical but accessible overview of his ideas:

Key idea: discrete Hilbert space

Traditional QM uses a continuous Hilbert space, an infinite-dimensional complex vector space. States are vectors with continuous parameters, allowing smooth superpositions.

Palmer replaces this continuous structure with a discrete version of Hilbert space. Instead of a smooth continuum of states, the state space has a rational or finite structure – meaning the allowed state vectors follow a discrete set of values, often linked to number theory or algebraic restrictions.

Motivation

Continuous mathematics often brings metaphysical baggage: infinities, idealizations, and conceptual puzzles like superposition (a system being in multiple states at once) and entanglement (spooky correlations across space).

By restricting quantum states to rational values embedded in a fractal-like discrete structure, Palmer aims to remove these metaphysical issues, offering a more “realist” and ontologically straightforward picture.

Rational state space and number theory

The discrete state space is based on rationals or algebraic numbers, which are countable and structured.

This leads to a fractal invariant set in a higher-dimensional space, something like a “skeleton” of allowed states. Systems evolve confined to this invariant set, avoiding non-physical or “counterfactual” states that the classical continuum allows but which never actually occur.

Explanation of quantum phenomena

Superposition: Instead of thinking of superposition as a physical state, we see it as a mathematical tool that approximates the underlying discrete structure.

Entanglement: Correlations corresponding to entangled states arise naturally within this rational framework due to the structure of allowed states, without invoking nonlocal “spooky action.”

This allows Palmer to reproduce Bell test results without assuming nonlocality or abandoning local realism. The key is that the discrete geometry restricts which measurement settings and outcomes can coexist, effectively removing hidden-variable loopholes without paradox.

Abandoning the classical continuum

The core price Palmer pays is dropping the classical idea that physical quantities exist on a continuous scale. Instead, he sees reality as fundamentally digital or “rational” at its core, even if it appears continuous when viewed at macroscopic scales.

This is a profound shift, which echoes some views in quantum gravity and information theory, where continuity is an emergent approximation rather than fundamental.

Summary

Palmer’s rational quantum mechanics proposes a discrete, fractal-like, rationally structured Hilbert space.

It reproduces the statistical predictions of quantum mechanics but with a fundamentally realist, non-mystical interpretation.

It claims to solve long-standing issues around superposition, entanglement, and Bell inequalities by changing the mathematical foundation, rather than adding interpretation layers.

This approach remains relatively new and is still being tested for full theoretical consistency and empirical adequacy.

If you want, I can also provide a simplified analogy or expand on specific aspects like how the fractal invariant set works or the treatment of Bell tests within this framework. Let me know!

AR I have long thought, like Stephen Wolfram, that continuous mathematics brings ontological baggage that physics is better off without, but never tried to think through a discrete physics rigorously. There must have been other people (perhaps Christopher Isham, for example) who have done so, yet the consensus still seems to remain that continuous Hilbert space is needed. Given recent work on quantum information theory, is it realistic to suppose we can get by with discrete approximations?

AI Your reflections touch on a deep and ongoing debate in the foundations of physics. Indeed, many thinkers like Stephen Wolfram, and others including Christopher Isham and various researchers in quantum gravity and quantum information theory, have explored discrete or alternative mathematical frameworks for physics. Here's an outline of the context and how your question fits into it:

Historical and conceptual context

Continuous mathematics has been incredibly successful in physics historically because calculus and differential equations accurately describe many natural phenomena.

Yet, from a philosophical and foundational perspective, the continuum raises questions. It introduces infinities and idealized structures that may not inherently correspond to physical reality.

Quantum theorists like Isham have explored quantum theory on discrete or finite structures, including quantum logic, algebraic quantum theory, and approaches where continuity is replaced by discrete spectra or finite-dimensional spaces.

Why continuity remains dominant

The standard formalism of quantum mechanics (based on continuous Hilbert spaces) fits well with experimental results and mathematical tools.

Certain phenomena, such as interference patterns and the smoothness of wavefunctions, seem naturally expressed with continuous variables.

Renormalization and effective field theory show how continuum theories emerge as approximations at large scales, reinforcing their practical use.

Discrete approximations and quantum information

Quantum information theory often works with finite-dimensional Hilbert spaces, such as qubits with 2-dimensional state spaces.

This practice shows that discrete quantum systems can represent key quantum phenomena and serve as computational/theoretical models.

However, the infinite-dimensional continuous Hilbert space formalism is still used for systems like quantum fields or particles in continuous space.

Can discrete approximations be fundamental?

Recent work, including that by Tim Palmer and others exploring discrete or finitary models, suggests that the continuum may be an emergent approximation.

Physical reality might be fundamentally digital or rational, with continuity arising only as a limit or large-scale approximation.

Quantum gravity and approaches like causal sets, loop quantum gravity, or cellular automata models share this view.

Yet, these alternate frameworks must prove they can reproduce known physics with precision and explain phenomena that continuous theory captures elegantly.

Realistic prospects today

It is realistic to explore discrete physics rigorously; quantum information provides a powerful lens because it naturally discretizes states and operations.

The main challenge is ensuring that discrete models can exactly reproduce continuum predictions where they are experimentally verified.

There is no firm consensus yet, largely because discrete theories are mathematically more complex and less mature in their development.

Also, discrete models often involve novel mathematics (fractals, number theory, algebraic structures) that are harder to interpret physically.

Summary

It is promising and realistic to suppose discrete quantum frameworks can underpin physics, at least conceptually.

Quantum information theory supports finite/discrete quantum models for many phenomena.

Extending discrete approaches to cover the full range of quantum phenomena – including fields, relativistic settings, and Bell tests – is an active research frontier.

The consensus favoring continuity is pragmatic but potentially subject to paradigm shift if discrete models like Palmer’s continue to deepen and prove successful.

If you’re interested, I can suggest key papers or perspectives from researchers working in discrete quantum theories and quantum gravity to explore this field more thoroughly. Would that be helpful?

AR Returning to your first response, I would be interest in learning more about how the fractal invariant set works or the treatment of Bell tests within this framework.

AI Certainly! Here’s a deeper yet accessible explanation of how the fractal invariant set and the treatment of Bell tests work in Tim Palmer’s rational quantum mechanics:

Fractal Invariant Set Theory (IST)

The fractal invariant set is a central mathematical object in Palmer’s model. Think of it as a special subset of the full state space where the system’s true physical states are confined.

This set is fractal: it has a complex, self-similar structure with intricate patterns repeated at every scale.

Importantly, this invariant set is non-computable and measure-zero in the continuous embedding space – meaning it occupies no volume in the mathematical continuum.

The system’s evolution is deterministic but confined strictly to this set; states outside the set are “non-physical” and thus never realized.

Therefore, physical reality corresponds only to points on this fractal invariant set, enforcing strong constraints on allowable states and their time evolution.

Why fractal?

Fractals have a rich enough structure to encode the complexity and apparent “randomness” seen in quantum measurements.

The fractal geometry enforces non-classical correlations inherently, without adding any mysterious nonlocal influences.

This fractal can be mathematically linked to rational representations and number-theoretic structures constraining allowed measurement outcomes and settings.

Treatment of Bell tests

Bell's theorem and associated experiments demonstrate that no local hidden-variable theory with classical assumptions can reproduce quantum correlations.

Traditional interpretations accept nonlocality or reject realism. Palmer's approach fully maintains locality and realism but drops the classical assumption of a continuous state space.

The fractal invariant set restricts the combinations of measurement settings and hidden variables possible in reality. This ensures that counterfactual states – those hypothetical but not actually realized states needed for classical Bell inequalities – do not lie on the invariant set.

Consequently, the Bell inequalities don't apply, because the assumption of all measurement settings being simultaneously well-defined (the classical "free choice" or measurement independence) is violated in a non-conspiratorial, physically natural way: The fractal invariant set geometry links measurement choices and hidden variables through rationality constraints.

This creates quantum correlations that mimic entanglement outcomes without "spooky action," because the outcomes are predetermined by restriction to the invariant set.

In this way, Palmer's theory is said to "explain" Bell test results with no violation of locality and without abandoning deterministic realism.

Summary

The fractal invariant set restricts reality to a special fractal subset of state space where only "rational" or allowed states exist.

This restriction prevents classical hidden variable assumptions underlying Bell inequalities. Bell test correlations emerge naturally from this constrained, fractal geometry while keeping locality and realism intact.

This reshapes fundamental quantum puzzles by replacing the classical continuum with an invariant fractal structure, avoiding the usual metaphysical paradoxes.

Would you like some illustrative analogies or a simpler metaphor to make the fractal invariant set idea more vivid?

AR Yes, this fractal subset of state space is new to me. But I'm surprised that no one else has seen this serendipitous effect on superposition, entanglement, and nonlocality before. How did Palmer arrive at this structure, and how does it appear naturally in the epistemology of quantum experiments?

AI Palmer's discovery of the fractal invariant set structure arises from deep interdisciplinary insights bridging dynamical systems theory, number theory, and quantum foundations, alongside careful consideration of the philosophical and physical meaning of measurement and state space. Here's how he arrived at it and why it feels natural in the context of quantum experiments:

How Palmer arrived at the fractal invariant set

Background in dynamical systems and chaos theory: Palmer's work stems from expertise in complex systems and chaos theory, where fractal invariant sets often characterize the long-term behavior of deterministic nonlinear systems. Such sets constrain trajectories to intricate subsets of a larger space with no volume and complex self-similarity.

Rethinking the state space of physics: Traditional quantum theory assumes a continuous infinite-dimensional Hilbert space. Palmer questioned this assumption, pondering whether the actual physical state space might be much smaller and more structured, resembling fractal invariant sets seen in classical chaos but in a quantum context.

Incorporation of number-theoretic constraints: By using rational and algebraic numbers instead of reals, Palmer imposed number-theoretic rationality constraints that severely limit which quantum states are physically possible. This is what gives the invariant set its fractal character and discrete nature – a step beyond simple coarse discretization.

Demand for a realist, local, and deterministic model: The fractal invariant set arose as a way to keep realism and locality intact in quantum physics, addressing violations of classical assumptions behind Bell inequalities by restricting the space of states and measurement settings in a physically meaningful way.

Why this structure is natural in the epistemology of quantum experiments

Finite precision in measurement: Actual quantum measurements always have finite resolution and practical limitations on settings. The invariant set can be seen as reflecting that only a subset of mathematically possible states and measurement choices correspond to physically realizable configurations.

Linking theory to observable data: The fractal structure encodes correlations and constraints that manifest in experimental outcomes as probabilistic quantum patterns – superposition and entanglement emerge effectively from this deeper deterministic structure.

Counterfactuals and “free choices” are idealizations: The fractal invariant set formalism suggests that counterfactual scenarios (what would have happened if a

different measurement were made) are not physically realizable states. This aligns naturally with careful epistemology: We only have access to the outcomes actually observed, not all conceivable alternatives.

Avoidance of metaphysical weirdness: By embedding physical states in this fractal subset, Palmer's model removes much conceptual discomfort around how superposition and entanglement are understood. Quantum states become "rational points" on an invariant set, rather than continuous waves that physically interfere or nonlocally correlate.

Summary

Palmer combined ideas from classical chaos (fractal invariant sets), rigorous mathematical restrictions (rationals over reals), and quantum measurement epistemology.

This synergy naturally led to a framework strong enough to reproduce quantum phenomena without traditional paradoxes.

It's "new" because it crosses several disciplines and challenges longstanding assumptions about the state space in quantum mechanics, leading to an interdisciplinary insight that took time to emerge.

If you'd like, I can share some historical background on similar ideas from other researchers and how Palmer's contribution fits into that broader tapestry. Would that be of interest?

AR Yes, it would, thanks.

AI Here's an overview of related historical and contemporary ideas in the foundations of physics and how Palmer's fractal invariant set theory fits into the broader quest for discrete or alternative quantum frameworks:

Early and mid-20th century foundations work

David Hilbert's continuum and classical foundations: The classical mathematical framework underlying quantum mechanics and physics has long relied on the continuum assumption – real numbers, continuous spaces, infinite-dimensional Hilbert spaces. Early debates about the nature of measurement and the meaning of probability set the stage for later philosophical puzzles.

Hidden variable theories and Bell's theorem (1960s and 70s): John Bell rigorously showed that any local and realistic hidden variable theory based on classical intuitions and continuous state spaces cannot reproduce all quantum predictions.

This spurred investigations into interpretations of QM (Copenhagen, many-worlds, de Broglie–Bohm) and fundamental assumptions like locality and realism.

Quantum logic and algebraic approaches

Christopher Isham and quantum logic: Isham explored reformulating quantum theory using algebraic structures and logic rather than classical continuous Hilbert spaces. His work involved using category theory and topos theory to generalize standard quantum mechanics, hinting at more fundamental discrete or logical underpinnings.

Finitary quantum theories and finite fields: Various researchers explored quantum theory over finite fields or discrete structures, often motivated by quantum computing or foundational puzzles. These models typically capture some phenomena but struggle to recover the full complexity of continuous QM, especially with relativistic fields.

Quantum gravity and discrete spacetime

Loop quantum gravity and spin networks: In modern quantum gravity, spacetime itself is posited to be discrete at the Planck scale, described by spin networks and combinatorial structures. These theories illuminate how classical spacetime and continuous fields might emerge from discrete, algebraic structures, a conceptual parallel to Palmer's approach at the quantum level.

Causal sets and cellular automata: Approaches that model spacetime and physical laws as based on discrete, evolving sets or automata also challenge the continuum. Stephen Wolfram's recent work echoes this philosophy, searching for fundamental discrete models generating observed complexity.

Palmer's contribution in context

Palmer's fractal invariant set theory uniquely synthesizes chaos theory, number theory, and quantum epistemology to propose a physically meaningful discrete structure.

Unlike many purely algebraic or abstract approaches, it concretely connects physical state restrictions with experimental consequences, especially around Bell test correlations.

It explains how physical reality is confined to a fractal subset, distinguishing it from continuous metaphysical possibilities – an idea less explored in earlier work.

His work can be seen as a modern synthesis rooted in solid mathematics, physics experiments, and foundational philosophy, making it a novel and promising path in the discrete quantum landscape.

Further reading suggestions

- Chris Isham’s papers on quantum logic and topos theory for foundational alternatives.
- John Bell’s original papers and later commentary on locality and realism.
- Review articles on quantum gravity discretization methods.
- Recent *New Scientist* coverage and Palmer’s own published papers explaining fractal invariant sets.

If you want, I can help point you to specific accessible articles or summaries by Palmer and others for a deeper dive. Does that sound helpful?

AR I'd like to read some reasonably accessible work on this by Palmer. Where do I start?

AI Tim Palmer has authored several papers that delve into his rational quantum mechanics framework, focusing on fractal invariant sets and their implications for quantum theory. Here are some accessible works to consider:

“Discretization of the Bloch sphere, fractal invariant sets and Bell’s theorem” (2020)

- This paper constructs a discretized version of the Bloch sphere, demonstrating how number-theoretic properties can encapsulate key quantum characteristics like complementarity, uncertainty relations, and entanglement. It also addresses the Kockens–Specker theorem and provides a physical interpretation of the fractal invariant set.

“Bell's conspiracy, Schrödinger's black cat and global invariant sets" (2015)

- In this work, Palmer proposes that a locally causal hidden-variable theory can violate Bell inequalities without invoking fine-tuning or retrocausality. He introduces the Cosmological Invariant Set Postulate, suggesting that physical reality resides on a non-computable, dynamically invariant fractal subset of the universe’s state space.

“The Invariant Set Postulate: A new geometric framework for the foundations of quantum theory and the role played by gravity” (2009)

- This foundational paper introduces the Invariant Set Postulate, proposing that cosmological states of physical reality belong to a non-computable fractal state-space geometry, invariant under deterministic causal dynamics. It explores the

implications for quantum physics, including contextuality and the emergence of complex numbers in quantum theory.

These papers provide a comprehensive introduction to Palmer's rational quantum mechanics and the concept of fractal invariant sets. They are accessible to readers with a background in physics and mathematics, offering insights into how discrete structures can address foundational issues in quantum theory.

AR This is very helpful. But I need more detail on the Invariant Set Postulate, short of reading paper (3) and without facing a paywall. Can you help?

AI Certainly! Here's a detailed but approachable explanation of Palmer's Invariant Set Postulate (ISP), unpacking its core ideas without needing the full technical paper:

What is the Invariant Set Postulate?

The ISP states that the physically real states of the universe lie on a special, fractal subset of the universe's entire mathematical state space – called the Invariant Set. This set has three key features:

Invariant: The set is stable under the universe's deterministic dynamics. Once a state is on this set, its evolution remains on it forever.

Fractal: The set is complex, self-similar at all scales, with a fine fractal geometry, meaning it's highly structured but occupies zero volume in the full state space.

Non-computable: Its structure is so intricate that it cannot be precisely enumerated or predicted by any finite algorithm – it's fundamentally beyond classical computation.

Why this matters for physics and quantum mechanics

The full state space (such as a big Hilbert space or classical phase space) mathematically includes states and histories that don't correspond to physical reality.

The ISP says only those states on the fractal invariant set are physically real or possible. States off the set are physically unrealizable.

This reduces the universe's allowed states drastically, by restricting reality to a highly constrained but deterministic structure.

Implications for quantum phenomena

Superposition and collapse: Quantum states traditionally live in continuous spaces allowing infinite superpositions. Under the ISP, superposition can be seen as arising from our approximation or embedding of these fractal states in a continuum. The fractal geometry naturally limits allowed states, avoiding paradoxical “multiple realities” or wavefunction collapse mysteries.

Entanglement and Bell tests: The fractal structure inherently restricts possible measurement settings and outcomes. Classical assumptions behind Bell inequalities fail, but this is not due to nonlocality or conspiracy. Instead, the geometry of the invariant set entangles local variables via number-theoretic constraints, explaining quantum correlations without “spooky action.”

Local realism and determinism: Unlike many interpretations that drop locality or determinism, ISP keeps both. The weirdness of quantum mechanics arises from the fractal constraints on physically possible states, not from abandoning classical principles.

How does the invariant set arise?

Palmer views the universe’s state space as a dynamical system evolving according to fundamental laws.

Over time, this evolution forces the system onto a fractal attractor – much like chaotic systems approach fractal structures.

This invariant set is not artificially imposed but is a natural geometric feature of the universe’s deterministic dynamics.

Epistemology and physical measurement

Because only fractal states are real, counterfactuals – states representing “what might have happened but didn’t” – often lie outside the invariant set and are meaningless physically.

This explains why classical hidden variable assumptions and measurement independence often fail without invoking fine-tuned conspiracy or denying free will.

Physical knowledge and measurement outcomes arise from intersections with this fractal set, grounding quantum probabilities in an ontological geometric structure.

Summary

The Invariant Set Postulate redefines physical reality as points on a fractal, deterministic but non-computable, invariant subset of all possible states.

This radically constrains the universe's allowed states, naturally addressing quantum puzzles around superposition, entanglement, and locality.

It bridges dynamical systems and number theory with quantum foundations, offering a fresh geometric and epistemological perspective without sacrificing locality or realism.

If you want, I can also guide you to some accessible video talks or summaries Palmer has given, which explain the idea in intuitive terms. Would that be useful?

AR That would be a nice final flourish, yes.

AI I'm glad to hear you're interested in exploring Tim Palmer's Invariant Set Theory further. Here are some accessible resources that delve into his ideas:

"Chaos theory and geometry: can they predict our world?" (2023)

– In this engaging Royal Institution lecture, Palmer discusses how fractal geometry and chaos theory can provide insights into various phenomena, including quantum physics. He introduces the concept of fractal invariant sets and their implications for understanding the universe's underlying structure. The talk is accompanied by a Q&A session that further elaborates on these concepts.

"Invariant Set Theory: A realistic causal approach for synthesising quantum and gravitational physics?" (2016)

– In this Perimeter Institute Colloquium presentation, Palmer explores how Invariant Set Theory offers a framework to synthesize quantum and gravitational physics. He discusses the role of fractal geometry in understanding the foundations of quantum theory and its potential to unify different areas of physics.

These resources should provide a solid foundation for understanding Tim Palmer's Invariant Set Theory and its applications.

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