Explanatory Depth and the Integration of Special Relativity and Quantum Mechanics

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Abstract

Despite nearly a century of development, quantum theories that address the special relativity-quantum mechanics tension still struggle with limited explanatory depth. Given the fundamental differences between the two core theories, this is not surprising. Quantum theories that rely on mathematical constructs to explain particle or quantum state dynamics often struggle to reconcile with special relativity's constraints in a physical 4D spacetime.

This paper explores the explanatory depth of a tightly integrated, physically grounded approach to reconciling special relativity and quantum mechanics based on a dual ontology framework where a discrete 4D spacetime and an ultra-high-dimensional space are integrated facets of a physically unified universe. The approach provides a theoretical framework that adheres to special relativity's laws, conforms with quantum experiments challenging special relativity's constraints, and establishes a physical one-to-one correspondence between quantum phenomena across both dimensions.

The strength of the analysis lies in its physical explanatory depth. Without relying on ad hoc, fine-tuning, or perturbative techniques, the model examines physical solutions for some of the most challenging special relativity-quantum mechanics problems, including (1) quantum entanglement and nonlocality, (2) the instantaneity of quantum collapse, (3) causality, (4) the nature of time, (5) quantum state localization, (6)) quantum tunneling, (7) the relativity of simultaneity, (8) relativistic energy increase, and (9) the Born Rule's relationship to special relativity's constraints.

Keywords: Explanatory Depth, Under-determinism, Special Relativity, Quantum Mechanics, Discrete 4D Spacetime

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1. Introduction

1.1. Explanatory Depth, Special Relativity, and Quantum Mechanics

Explanatory depth is an essential tool for evaluating the validity of theories that address the tension between special relativity (SR) and quantum mechanics (QM). During the past 100 years, resolving the tension has appeared so intractable that few theories directly engage with it, and those that approach the tension rely on complex mathematical constructs that do not easily align with the constraints of SR. The D.O. model presents a fresh perspective on the SR-QM tension. Based on an integrated, discrete 4D spacetime and a physical, ultra-high-dimensional space, the analysis departs from historical abstract spaces like Hilbert, Fock, or 3N configuration spaces. The D.O. model addresses the SR-QM tension directly and does so without ad hoc assumptions, fine-tuning, or perturbative techniques, grounding quantum phenomena in ontologically consistent physical processes.

Any theory that addresses the SR-QM tension should ideally explain quantum state dynamics in compliance with both SR and general relativity (GR) while also addressing quantum experiments that appear to violate SR. In order to reconcile SR and QM comprehensively, a unified theory should provide physical explanations for a range of fundamental issues. At a minimum, the theory should address 1) quantum entanglement and nonlocality, 2) the instantaneity of quantum collapse, 3) causality, 4) the nature of time, 5) space-like separation, 6) separability, 7) indeterminism, 8) quantum state emergence and annihilation, 9) quantum state localization, 10) quantum tunneling, 11) the relativity of simultaneity, 12) relativistic energy increase, 13) quantum non-attenuation and quantum exclusivity, and 14) the Born Rule's relationship to SR.

1.2. 4D Spacetime's Incompatibility with Current Quantum Theories

Neither SR nor GR, developed in the early 20th century, directly addresses QM. Despite the rapid development of quantum theories post-Einstein, integrating SR and QM has had little success. Frameworks like Schrödinger's wave mechanics, Heisenberg's matrix mechanics, and Feynman's path integral[2] assume low velocities, ignoring relativistic effects. Most variations of the Copenhagen Interpretation[3], Bohmian mechanics[4], objective collapse theories[5] (GRW$_f$, GRWm, CSL), MWI[6], the Transactional Interpretation[7], and others[8] rely on

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[2] While Feynman’s original path integral formulation was non-relativistic, he later adapted the framework for relativistic quantum field theory.

[3] (Howard, 2004).

[4] (Dürr et al., 1995); (Goldstein & Zanghi, 2011).

[5] (Bassi & Ghirardi, 2003); (Bassi et al., 2012).

[6] (Deutsch, 1985); (Wallace, 2012); (Vaidman, 2021).

[7] (Cramer, 1986).

[8] (Allori, 2013b); (Fuchs et al., 2014); (Griffiths, 2003); (Hubert & Romano, 2018); (Norsen et al., 2015); (Rovelli, 1996).

modified versions of the non-relativistic Schrödinger equation or Hilbert space.[9] Relativistic quantum field theories (QFT) typically rely on flat Minkowski spacetime**,** ignoring GR's curved framework, and continue to depend on abstract constructs like Hilbert and Fock space without resolving the SR-QM conflict.[10]

1.3. Mathematical Formulations and Physical Ontologies

Sophisticated mathematical formulations that govern theory structure can sometimes obscure the underlying physical ontology. GRWf, GRWm, CSL, and Multi-Field Theories present consistent frameworks but are *semi-ontological*, where mathematics functions as part of the ontology itself. In these cases, mathematical structures are treated as if they were ontic components, complicating reconciliation with the physical requirements of SR.

In contrast, MWI, Transactional Interpretations, Relational Quantum Mechanics, and other frameworks, including Consistent Histories and Quantum Bayesianism, lack a clear physical mechanism to reconcile with SR or treat quantum states as mathematical or relational entities without ontic status in 4D spacetime. QFTs relying on Hilbert or Fock Spaces to describe physical 4D spacetime face the same ontological challenge.

Whether mathematical or *semi-ontological*, these quantum theories underscore the philosophical issue of underdetermination. Reifying ultra-high dimensional mathematical spaces or blurring the boundary between mathematics and ontology complicates the underdetermination problem. As a result, multiple models explain the same data but often lack grounding in an ontology that corresponds with the physical laws of 4D spacetime.

Theories based on Hilbert space, Fock space, phase spaces, or 3N configuration spaces further complicate the problem by combining ontic elements with mathematical structures, often leading to unphysical conclusions. For example, while 4D spacetime alone cannot fully explain the dynamics of N-body quantum states, many mathematical approaches model N-body quantum states as if they evolve within non-physical ultra-high-dimensional spaces. Though mathematically successful, these approaches raise ontological issues: N-body quantum states (including cats) do not technically exist within 4D spacetime. Additionally, the lack of a one-to-one correspondence between quantum states in a low-dimensional 4D spacetime and mathematical ultra-high-dimensional spaces makes a coherent connection between the two realms impossible.[11]

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[9] For discussions on 3N ontic spaces, see (Albert, 2013); (Ney, 2021); (Ney, 2023).

[10] See generally (Carroll, 2022).

[11] (Monton, 2002, 2006). See also (Ney, 2021).

1.4. The D.O. Model

The Dual Ontology (D.O.) model addresses the limitations of quantum theories by introducing a fully physical framework that integrates a discrete 4D spacetime with a physical ultra-high dimensional *Planck Dimension*.[12] Uniquely, this framework complies with SR's constraints and preserves GR's causality and background independence without conflicting with GR's core structure.

Unlike quantum theories that rely on mathematical spaces such as Hilbert, Fock, or 3N configuration spaces, the D.O. model ensures that both single and N-body quantum states exist as ontic entities in both 4D spacetime and the Planck Dimension.[13] Moreover, all physical laws, including SR, apply equally to single and N-body quantum states. This approach avoids the ontological challenges associated with mathematical, high-dimensional spaces that restrict N-body quantum states to a non-physical existence.[14] The model offers significantly greater explanatory depth than prior theories that have not fully reconciled the core differences between SR and QM and, at the same time, addresses the underdetermination problem of QM.[15]

2. The Ontological Framework of the D.O. Model

Section 2 introduces the D.O.'s novel ontological framework. The D.O. model consists of two physical structures: a discrete 4D spacetime[16] and a physical ultra-high-dimensional Planck Dimension. Both 4D spacetime and the Planck Dimension are composed of two ontological substructures: discrete spatial units referred to as Discrete Spheres and a State of Absolute Nothingness (SOAN). Discrete Spheres and the SOAN both play critical roles in the physical integration of 4D spacetime and the Planck Dimension, creating a unified model that resolves the tension between SR and QM.

2.1. Discrete Spheres

Under the D.O. model, Discrete Spheres are quantized, three-dimensional units of space that form the discrete structure of 4D spacetime and the ultra-high-dimensional structure

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[12] See (Monton, 2002, 2006).

[13] Under the D.O. model, subatomic entities are quantum states, not particles. The mathematical wavefunctions that describe the dynamic evolution and collapse of all quantum states in 4D spacetime are not ontic. (Maudlin 2013b, 2019); (Monton, 2006); (Pusey et al., 2012). See generally (Gao, 2016).

[14] See (Einstein et al., 2011); Howard, 1990. See (Albert, 2013), (Chen, 2019), and (Ney, 2021, 2023) for alternative views regarding a wavefunction in 3N dimensional spaces.

[15] The experimental depth of the D.O. model is premised on its ontology, dynamics, mathematical formalisms, and its ability to resolve the SR-QM tension. See generally (Maudlin, 2019).

[16] Whether 4D spacetime is a continuous or discrete space is an unsettled subject. (Crouse, 2016); (Hagar, 2015); (Hossenfelder, 2013, 2014); (Smolin, 2004).

of the Planck Dimension. Each Discrete Sphere has an identical shape and volume and represents the smallest structural quanta of space.[17] Each Discrete Sphere maps to and is identified by a separate set of x, y, z coordinates. Discrete Spheres can hold energy and collectively hold all the energy in the universe.

The dual presence of each Discrete Sphere in both 4D spacetime and the Planck Dimension, facilitated by the SOAN (see Section 2.2 below), is referred to as the *Planck Identity*. The identity's one-to-one mapping ensures that each Discrete Sphere is simultaneously identified and mapped to the same x, y, z coordinates in both dimensions.[18] As a core structural concept, the Planck Identity supports the model's tightly integrated, unified framework.

2.2. The SOAN

The concept of *nothingness* has long perplexed philosophers and scientists. Greek and Roman thinkers struggled with the ideas of zero and the void. Although these concepts no longer trouble physicists, *nothing* is now often used metaphorically to mean *not anything* rather than an ontic state of nonexistence. For example, in GR, nothing, as in not anything, is used metaphorically to describe what 4D spacetime expands into after its inception at t = 0. This use of nothing has no independent physical reality. Consistent with the idea that 4D spacetime does not expand into a pre-existing space, nothing is also used to denote the absence of both space and time.[19]

The term nothing has also been used in the context of quantum gravity. Loop Quantum Gravity, for example, applies the concept of nothing to the interstices of discrete spin networks. Here, nothing, as in not anything, exists in the interstices of spin networks.[20]

Under the D.O. model, the SOAN's only defining attribute is onticness; it lacks any other physical properties. Despite its abstract nature, an ontic SOAN is an essential component of the D.O. framework. As used in this analysis, the SOAN is devoid of:

> Space, time, dimension, boundary, size, structure, volume, gravity, energy, pressure, temperature, force, fields, ground states, vacuum states, virtual particles, quantum fluctuations, dynamic properties, frame of reference, matter, strings, information, mathematical entities, potentials, concepts, abstractions, consciousness, positive physical laws, possibilities, or entropy.[21]

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[17] For illustrative purposes, Discrete Spheres have a volume of 2.2 x 10^{-105} meters.

[18] See Chen (2017).

[19] Interview with Sean Carroll, Vice Magazine Online. "What is Nothing?" with Nick Rose, October 31, 2018.

[20] (Rovelli, 2017, p. 152).

[21] See (Barrow, 2001); (Grunbaum, 2009); (Holt, 2012); (Leslie & Kuhn, 2013); (Moghri, 2020). An ontological SOAN turns one of the greatest philosophical questions of all time on its head. The question is not 'Why is there something rather than nothing?'; rather, it is; **Why is there something AND nothing?**

Given its restrictive definition, the SOAN is a passive ontological entity with no active role in the universe. Since it lacks any physical attributes beyond onticness, the physical laws governing 4D spacetime and the Planck Dimension do not apply to it. It cannot be observed or measured, has no structure, boundaries, space, or time, and is not governed by the laws of physics. The absence of these characteristics is a defining feature, not a limitation, making the SOAN essential for structurally supporting the universe's physical structure and dynamics. By providing a non-spatial, non-temporal link, the SOAN's lack of physical properties is crucial since it bypasses spatial, temporal, and physical constraints and enables Discrete Spheres to exist simultaneously in 4D spacetime and the Planck Dimension.

Counterintuitively, it is the SOAN's onticness that links Discrete Spheres in 4D spacetime with those in the Planck Dimension. The one-to-one identity and mapping between Discrete Spheres across these dimensions depend on the link. The Planck Identity ensures that the x, y, z coordinates of a Discrete Sphere in 4D spacetime correspond to the physical characteristics of the same Discrete Sphere in the Planck Dimension. This link supports simultaneous quantum dynamics: the evolution of single and N-body quantum states in 4D spacetime, compliant with SR, and the instantaneous collapse of quantum states in the Planck Dimension, where the laws of 4D spacetime do not apply.

Serving as the cornerstone of the D.O. model's explanatory framework, the SOAN enables a coherent, physical approach to the SR-QM tension. The explanatory depth that emerges from this model provides a pragmatic basis for evaluating the SOAN's ontic significance.

2.3. Discrete 4D Spacetime

Unlike GR's conception of 4D spacetime as a continuous, differentiable manifold, the D.O. framework posits that 4D spacetime is discrete. Nevertheless, the Dual Ontology's structure and dynamics are deeply rooted in a physical 4D spacetime governed by the laws of SR and GR. This incorporation is fundamental to the D.O.'s explanatory depth and its minimization of the underdetermination problem.

Mathematically, incorporating a discrete 4D spacetime structure, dynamics, and physical laws within the D.O. model alters, but does not fundamentally change, the classical laws of physics. The D.O. replaces the linear, non-relativistic Schrödinger equation with mathematical formalisms for discrete Maxwell, Dirac, and Klein-Gordon equations, a modified Regge Calculus for discrete spacetime, discrete Einstein field equations for a curved, discrete spacetime, and specific laws governing quantum state evolution and collapse. Despite these modifications, the D.O. model is explicitly background-independent.[22]

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[22] See Appendix A for mathematical formalisms that support the D.O. framework.

Physically, a discrete 4D spacetime is essential not only for a unified ontology of 4D spacetime and the Planck Dimension but also for the one-to-one identity and mapping between Discrete Spheres in both dimensions. As discussed in Section 3, the one-to-one identity and mapping support the D.O.'s premise that single and N-body quantum states are ontic in both 4D spacetime and the Planck Dimension. It also explains why all quantum states evolve in 4D spacetime according to the laws of GR and SR.

2.4. The Planck Dimension

The Planck Dimension is the second core ontological structure in the D.O. model. As is the case in a discrete 4D spacetime, the Planck Dimension is composed of Discrete Spheres and the SOAN. Mathematically, the Planck Dimension is composed of N-tuples of ordered triples: $Q_n = \{(x_1,y_1,z_1), (x_2,y_2,z_2),...,(x_n,y_n,z_n)\}$where each N-tuple represents the three (x, y, z) spatial dimensions of a Discrete Sphere.

The total number of Discrete Spheres that make up the Planck Dimension is denoted by N, and the total number of dimensions in the Planck Dimension is (3 x N), where the 3 refers to the three spatial dimensions of each Discrete Sphere.[23] In the Planck Dimension, each N-tuple corresponds to three dimensions, and collectively, all the N-tuples collectively form the Planck Dimension's structure. Unlike continuous manifold configurations, such as 3N or ontic spaces composed of mutually orthogonal vectors, the ultra-high-dimensional (3 x N) Planck Dimension integrates N Discrete Spheres into a single *Planck Point*. For example, the 5.58×10^{186} Discrete Spheres that comprise the observable portion of discrete 4D spacetime form a single Planck Point composed of $(3 \times 5.58 \times 10^{186})$ dimensions.

Although both the Planck Dimension and 4D spacetime are composed of the same Discrete Spheres, fundamental ontological and dynamic differences exist between a low-dimensional 4D spacetime and the ultra-high-dimensional (3 x N) Planck Dimension. Unlike 4D spacetime, the Planck Dimension has no time dimension,[24] no physical properties of space, and no volume, and the laws of GR and SR, the strong nuclear force, the electro-weak force, or thermodynamics do not govern it. Concepts like kinetic energy, potential energy, and entropy also do not apply to the Planck Dimension.

These fundamental differences between the Planck Dimension and 4D spacetime are central to the Dual Ontology and critical to resolving the SR-QM tension.

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[23] See (Lewis, 2013, p. 116) for an early use of an ultra-high dimensional (3 x N) space.

[24] See (Adams, 2019, p. 158).

2.5. The Tightly Integrated D.O. Model

The combination of a discrete 4D spacetime and a (3 x N) Planck Dimension form the D.O's single, tightly integrated ((3 x N) +3) physical model. The Discrete Spheres that constitute both 4D spacetime and the Planck Dimension are linked by the SOAN, which serves as a non-spatial, non-temporal bridge between the two dimensions.

Although the D.O.'s ((3 x N) +3) structure may initially appear complex, its core is much simpler. Based on an ontic SOAN, the D.O. framework links a discrete 4D spacetime and the Planck Dimension into a single physical structure, forming a unified Dual Ontology framework that exists in the same location as 4D spacetime. More proverbially, 4D spacetime does not exist 'here,' and the Planck Dimension does not exist 'there'; they co-exist in the same physical space.

For example, imagine that discrete 4D spacetime consists of Discrete Spheres and that the SOAN exists within the interstices of these spheres. Next, assume there are five Discrete Spheres: one on Venus, one on Mars, one in the Milky Way, one in the Andromeda Galaxy, and one in the Orion Constellation. In 4D spacetime, the Discrete Spheres are spatially separated, and each is represented by a set of x, y, z coordinates. However, since the SOAN, rather than space, exists in the interstices between Discrete Spheres, from the perspective of the Planck Dimension, these five spheres are not separated by time, space, or volume. Instead, the Planck Identity holds that they simultaneously comprise five Discrete Spheres in the Planck Dimension. In the Planck Dimension, the five Discrete Spheres form a single, unified 15-dimensional point (3 x 5), where the 3 represents the three spatial dimensions of each sphere and the 5 represents the five spheres.[25]

2.6. The Planck Identity and Quantum States

The significance of the Planck Identity's one-to-one identity and mapping between 4D spacetime and the Planck Dimension extends beyond the integration of 4D spacetime and the Planck Dimension in two essential ways. First, the Planck Identity ensures that N-body quantum states, which cannot be fully captured in 4D spacetime alone, are simultaneously identified and mapped in both 4D spacetime and the Planck Dimension without relying on mathematical constructs. Unlike many quantum theories that represent N-body quantum states through high-dimensional mathematical spaces, the D.O. model provides a physical framework where quantum states are ontic in both 4D spacetime and the Planck Dimension.

Second, any dynamic changes in the physical characteristics of single or N-body quantum states are mirrored instantaneously in both 4D spacetime and the Planck Dimension.

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[25] The Planck Identity can be expressed as a function f mapping from 4D spacetime R^4 to the (3 x N) dimensional Planck Space $R^{3\times N}$: f: $R^4 \rightarrow R^{3\times N}$. For a set of coordinates (x_i,y_i,z_i,t_i), the function f maps these coordinates to $f((x_i,y_i,z_i,t_i)) = ((x_{i1},y_{i1},z_{i1}),(x_{i2},y_{i2},z_{i2}),\ldots,(x_{iN},y_{iN},z_{iN}))$ where each Planck Sphere represents a separate 3-dimensional space in the Planck Dimension. Planck Space does not have an independent time parameter.

As a quantum state evolves in 4D spacetime, its physical changes are mirrored in the Planck Dimension. Similarly, when a quantum state collapses in the Planck Dimension, the corresponding changes are mirrored in 4D spacetime. This dynamic symmetry across both dimensions is critical to resolving the SR-QM tension within the D.O. framework.

Section 3 explores these relationships further by re-examining classical quantum experiments in light of the D.O. model.

3. The D.O. and the Dynamics of Quantum States

3.1. The Dynamic Evolution of a Single Quantum State

The analysis begins with the dynamic evolution of a single quantum state in a discrete 4D spacetime composed of Discrete Spheres and the SOAN. The Planck Identity holds that the x, y, z coordinates of every Discrete Sphere in 4D spacetime simultaneously identify and map to the same Discrete Sphere in the Planck Dimension. As a quantum state evolves in 4D spacetime, it occupies a large number of Discrete Spheres, each containing quantized energy. The combination of a single Discrete Sphere and its energy is referred to as a *Bell Sphere*. Building on the Planck Identity, the *Bell Identity* is a central concept in the D.O. model, establishing a one-to-one identity and mapping between a Bell Sphere in 4D spacetime and the Planck Dimension.[26]

In 4D spacetime, the collective Bell Spheres occupied by a quantum state constitute its Bell Field, while in the Planck Dimension, the same Bell Spheres form the quantum state's single, ultra-high-dimensional *Bell Point*. For example, in the ground state of an electron in a hydrogen atom, the 1.92×10^{74} Bell Spheres simultaneously comprise the electron's Bell Field in 4D spacetime and its single ($3 \times 1.92 \times 10^{74}$)-dimensional Bell Point in the Planck Dimension. The physical attributes of the quantum state, including its energy, are represented in both 4D spacetime and the Planck Dimension.[27]

As a quantum state spreads in 4D spacetime, the number of Bell Spheres it occupies increases. The Bell Identity ensures a corresponding increase in the number of Bell Spheres that comprise the quantum state's Bell Point in the Planck Dimension.

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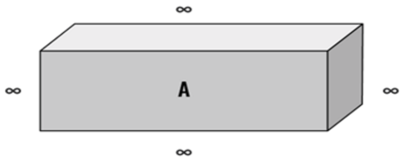
[26] The Bell Identity can be expressed as a function g mapping from 4D spacetime R^4 to the (3 x N) dimensional Planck Dimension $R^{3\times N}$: g: $R^4 \to R^{3\times N}$. For a set of coordinates (x_i,y_i,z_i,t_i), the function g maps these coordinates to: $g((x_i,y_i,z_i,t_i)) = ((x_{i1},y_{i1},z_{i1}),(x_{i2},y_{i2},z_{i2}),\ldots,(x_{iN},y_{iN},z_{iN}))$ where each Bell Sphere represents a separate 3-dimensional space in the Planck Dimension.

[27] See Appendix A, section 3.1 for the general dynamic evolution law under the D.O. model.

3.2. The Collapse of a Single Quantum State

In addition to linking the dynamic evolution of a quantum state's Bell Field in 4D spacetime with its Bell Point in the Planck Dimension, the Bell Identity also links the instantaneous collapse of a quantum state’s Bell Point in the Planck Dimension with its Bell Field in 4D spacetime. Accordingly, the identity ensures that the instantaneous decrease in the number of Bell Spheres comprising a quantum state’s Bell Point is mirrored by a simultaneous reduction in the number of Bell Spheres forming its Bell Field in 4D spacetime.[28]



For example, assume that quantum state A is placed within impenetrable Box A with zero potential inside. Quantum state A forms Bell Field A in 4D spacetime and a corresponding Bell Point A in the Planck Dimension. As quantum state A spreads, the Bell Identity ensures that any increase in the number of Bell Spheres in Bell Field A is mirrored by a corresponding increase in the number of Bell Spheres in Bell Point A. The opening of Box A triggers the instantaneous collapse of Bell Point A, causing an instantaneous reduction in the number of Bell Spheres in the Planck Dimension. Simultaneously, Bell Field A mirrors the reduction in the number of Bell Spheres. The instantaneous reduction in the number of Bell Spheres that comprise Bell Field A ensures that quantum state A is instantaneously localized within Box A, but the physical laws of SR have not been violated. [29]

3.2.1. The Einstein/de Broglie Boxes Thought Experiment

The Einstein/de Broglie thought experiment[30] further illustrates the dynamics of a quantum state. Quantum state B is generated, forming Bell Field B in 4D spacetime and its corresponding Bell Point B in the Planck Dimension. Quantum state B is inserted into Box B, where it begins to spread, occupying an increasing number of Bell Spheres in both 4D spacetime and the Planck Dimension.[31]

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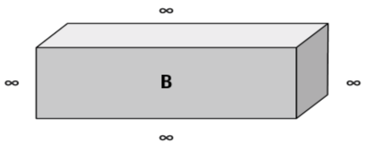
[28] See Appendix A, section 3.1, for the general collapse law under the D.O. model.

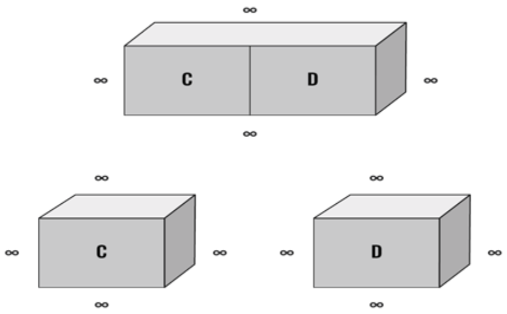
[29] See (Gao, 2019) regarding the incompatibility of unitary quantum theories and relativity. Significantly, the Bell Identity ensures unitarity throughout the dynamic evolution of all quantum states in 4D spacetime and their collapse in the Planck Dimension, which, as a direct consequence, solves the tails problem. See generally (McQueen, 2015).

[30] See (Allori, 2022); (Bricmont, 2016); (Broglie, 1964); (Norsen, 2005).

[31] See Appendix A, section 3.2, for the mathematical dynamic formalism for a single quantum state.



An impenetrable divider is inserted into Box B, creating Box C and Box D. The quantum state now forms two equal Bell Fields in 4D spacetime, Bell Field C and Bell Field D, and a single Bell Point in the Planck Dimension, designated as Bell Point CD. Box C is sent to Princeton, and Box D is sent to Copenhagen. Despite their separation, the Bell Identity ensures the quantum state continuously forms Bell Fields C and D in 4D spacetime and Bell Point CD in the Planck Dimension.



When either Box C or Box D is opened, Bell Point CD instantaneously collapses, and the number of Bell Spheres that comprise the quantum state in 4D spacetime and the Planck Dimension is instantly reduced. If the quantum state is found in Box C, the quantum state forms Bell Field C in Box C and Bell Point C in the Planck Dimension. Bell Field D and Bell Point D no longer exist. Conversely, if the quantum state is found in Box D, it forms Bell Field D in Box D and Bell Point D in the Planck Dimension, and Bell Field C and Bell Point C no longer exist. The process is the same regardless of which box is opened first.[32]

3.2.2. The Double-Slit Experiment

In the double-slit experiment, individual quantum states, such as electrons, are directed at Wall (W), which has two narrow Gaussian slits (A) and (B). Due to the narrowness of the slits, every quantum state that passes through slit (A) or slit (B) diffracts. Some quantum states hit the wall, while others pass through the slits, spreading as spherical waves toward Detector D and creating an interference pattern over time.[33]

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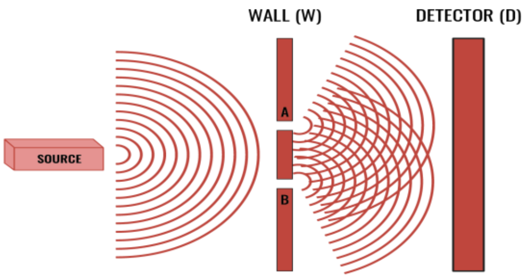
[32] See Appendix A, section 4.2, for the mathematical collapse formalism for a single quantum state.

[33] See Appendix A, section 3.2, for the mathematical dynamic formalism for the double slit experiment.



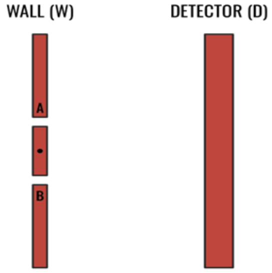
Double Slit Diffraction

As a quantum state diffracts through slit (A) and slit (B), its Bell Field splits into two separate fields in 4D spacetime, Bell Field A and Bell Field B. In the Planck Dimension, however, the fields continuously remain unified as a single Bell Point AB.[34]

When the diffracted quantum state reaches Detector (D), Bell Point AB collapses, resulting in a single detection flash from either Bell Field A or B, while the other ceases to exist. The instantaneous collapse of a quantum state's Bell Point ensures that the entire quantum state is generally localized in 4D spacetime. The interference pattern at Detector (D) arises from the cumulative effect of individual quantum state collapses.[35]

3.2.3. A Which-Way Experiment

Which-way experiments compound the theoretical complexities of the double-slit experiment. The following which-way experiment has been modified by including a proton in an empty box at the center of Wall (W).[36] The proton is positively charged, and each electron fired toward Wall (W) is negatively charged. Slit (A) flashes if the proton is attracted toward slit (A), and slit (B) flashes if it is attracted toward slit (B).



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[34] Double-slit experiments describe a quantum state by its wave function rather than the considerably more amorphous terms charge density or energy content. Nevertheless, since all quantum states are ontic, if an electron passes through slits A and B, the charge density, and the energy content of the electron, however ill-defined, must also do so. See (Sebens, 2021).

[35] See Appendix A, section 4.2, for the mathematical collapse formalism for the double slit experiment..

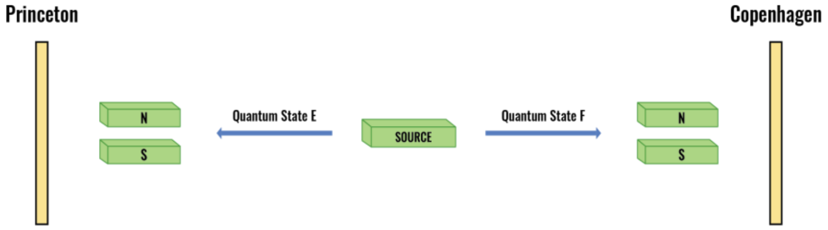
[36] The which-way monitoring experiment is based upon the example presented in (Maudlin, 2019, pp. 14-16).

Under the D.O. model, as the quantum state spreads in 4D spacetime, it continuously forms a Bell Field in 4D spacetime and simultaneously forms a single Bell Point in the Planck Dimension. If slit (A) flashes, the quantum state's Bell Point instantly collapses, reducing the number of Bell Spheres that make up its new Bell Point and Bell Field. The quantum state is now generally localized at slit (A). The analysis is the same if slit (B) flashes rather than slit (A).

Once the quantum state is generally localized at either slit (A) or slit (B), it again spreads toward Detector (D). However, since the quantum state collapses at either slit (A) or slit (B), but not both, no interference pattern forms at Detector (D).

3.3. N-Body Quantum States and The Bohm-EPR Thought Experiment

The Bohm version of the EPR experiment highlights issues related to the dynamic evolution of an N-body quantum state in 4D spacetime and its collapse in the Planck Dimension.[37] A pair of electrons is prepared in the singlet state. The singlet state forms Bell Fields E and F in 4D spacetime and Bell Point EF in the Planck Dimension. Quantum state E is sent toward Princeton, and quantum state F is sent toward Copenhagen. Testing equipment is configured to conduct a z-axis Stern-Gerlach experiment on either Bell Field E or F.



As Bell Fields E and F dynamically spread in 4D spacetime, the number of Bell Spheres that comprise their respective Bell Fields increases, as does the number of Bell Spheres that comprise Bell Point EF.[38] Following a Stern-Gerlach experiment in the z-axis in either Princeton or Copenhagen, Bell Point EF collapses.[39] The collapse instantaneously reduces the number of Bell Spheres that formerly composed Bell Point EF, Bell Field E, and Bell Field F, respectively.[40] Bell Point EF now forms two independent Bell Points designated as Bell Point

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[37] (Bohm, 1951a).

[38] See Appendix A, sections 3.3 and 3.4, for dynamic evolution formalisms for the EPR experiment.

[39] Although the Stern-Gerlach experiment in the z-axis is conducted in 4D spacetime, on either Bell Field E in Princeton or Bell Field F in Copenhagen, the Bell Identity ensures that the experiment is simultaneously reflected on Bell Point EF in the Planck Dimension.

[40] See Appendix A, sections 4.3 and 4.4, for collapse formalisms for the EPR experiment.

E and Bell Point F. Bell Point E shares a one-to-one mapping and identity with Bell Field E, and Bell Point F shares a one-to-one mapping and identity with Bell Field F.[41]

Following the collapse, Bell Point E and Bell Point F form a product state rather than an entangled state $\psi_{1,2}((x_1,y_1,z_1)_{1,}(x_2,y_2,z_2)_2) \rightarrow \psi_1(x_1,y_1,z_1)_1 \otimes \psi_2(x_2,y_2,z_2)_2$, and Bell Field E and Bell Field F are instantaneously localized. Whether quantum state E is found in the z spin-up or z spin-down axis, quantum state F's spin will be the opposite. Despite the space-like separation of the quantum states, the collapse of Bell Point EF does not violate SR.

4. Physical Implications of the D.O. Model

4.1. Indeterminacy

In the D.O. model, indeterminacy means a quantum system has a determinable property without a specific determinate value for it.[42] In a singlet state along the z-axis, spin is a determinable property, with z spin-up and z spin-down as determinate values. When quantum states z_1 and z_2 form a singlet state $\psi = \frac{1}{\sqrt{2}} (\uparrow z_1 \downarrow z_2 - \downarrow z_1 \uparrow z_2)$, the Bell Identity ensures that the singlet state forms a single Bell Point in the Planck Dimension and two corresponding Bell Fields in 4D spacetime. The D.O. framework ensures the physically indeterminate status of the singlet state until the quantum state collapses. After the singlet state instantaneously collapses, the quantum state transitions to a product state, where the spins of z_1 and z_2 become determinate, represented by either $\psi \rightarrow \uparrow z1 \downarrow z2$ or $\psi \rightarrow \downarrow z1 \uparrow z2$. Each quantum state now forms a unique Bell Point associated with its respective localized Bell Field in 4D spacetime. [43]

4.2. Quantum State Emergence and Annihilation

Quantum state emergence and annihilation challenge the non-relativistic Schrödinger equation's reliance on static quantum spaces with a fixed number of quantum states.[44] Relativistic quantum field theory (QFT) addresses these variations, but the D.O. model offers a unique solution, representing quantum states as physical entities in both 4D spacetime and the Planck Dimension.

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[41] For an N-body quantum state, the Bell Identity can be mathematically formulated as a function *h* that maps from 4D spacetime R^4 to a (3 x N) dimensional Planck Dimension $R^{3\times N}$. The function *h* is defined as: $h: R^4 \rightarrow R^{3\times N}$. Given a set of coordinates in 4D spacetime $(x_{j1},y_{j1},z_{j1},t_{j1})$, $(x_{j2},y_{j2},z_{j2},t_{j2}),\ldots,(x_{jk},y_{jk},z_{jk},t_{jk})$, occupied by an N-body quantum state the function *h* maps these coordinates to $h((x_{j1},y_{j1},z_{j1},t_{j1}), (x_{j2},y_{j2},z_{j2},t_{j2}),\ldots, (x_{jk},y_{jk},z_{jk},t_{jk})) = ((x_{j1},y_{j1},z_{j1}), (x_{j2},y_{j2},z_{j2}),\ldots,(x_{jk},y_{jk},z_{jk}))$ where each Bell Sphere represents a single 3-dimensional point.

[42] (Lewis, 2016, pp. 72-107).

[43] In the Planck Dimension, a single Bell Point is neither space-like separated nor a separable system. See Sections 5.1 and 5.2 below. See also (Ney, 2021, pp. 112-128); (Howard, 1985, p. 197).

[44] For a detailed discussion, see (Ney, 2021).

Under the D.O. framework, the Bell Identity links the Bell Spheres that compose the quantum state's Bell Field in 4D spacetime and its Bell Point in the Planck Dimension. With approximately 10^{90} quantum states in the observable universe, the potential combinations of Bell Spheres are vast. For example, a single quantum state's Bell Field in the ground state of a hydrogen atom would occupy about 1.92×10^{74} Bell Spheres—a small number compared to the 5.58×10^{186} Discrete Spheres across the observable universe.

In quantum annihilation, the collapse of a quantum state's Bell Point transfers its properties—such as energy or momentum—to another system, eliminating the original state's Bell Point and Bell Field and nullifying its wave function. Conversely, quantum emergence involves the formation of a new Bell Field in 4D spacetime and a corresponding Bell Point in the Planck Dimension, establishing a new quantum state as its properties, such as energy or momentum, form a quantum state within the D.O. framework.

4.3. Physical Triggers

In the D.O. model, the Bell Identity ensures that any change in the physical characteristics of the Bell Spheres that form a quantum state's Bell Field in 4D spacetime is mirrored by the quantum state's Bell Point in the Planck Dimension. In 4D spacetime, *Physical Interactions* arise from one or more of the traditional Fundamental Forces: electromagnetism, the strong nuclear force, the weak nuclear force, and gravitational spacetime warping. Consequently, the Fundamental Forces govern not only all quantum state motion in 4D spacetime but also all Physical Interactions between quantum states, including all physical triggers that initiate the collapse of a quantum system in the Planck Dimension.[45]

The D.O. model does not identify a precise Physical Interaction that induces quantum state collapse. Nevertheless, it offers a structured framework to investigate how these physical triggers may initiate collapse. Within this framework, each Physical Interaction is an independent event localized in time and space, with its frequency influenced by factors such as temperature and spatial positioning.[46] For example, local temperature and position within the Sun affect the rate of quantum state collapse. Humans can initiate or influence the timing and location of Physical Interactions.[47] However, Physical Interactions are independent of human consciousness, ambient noise, universal processes, or probability-based rules.[48]

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[45] The concepts of gravity, the strong nuclear force, and the electro-weak force do not exist in the Planck Dimension.

[46] See generally (Licata & Chiatti, 2019).

[47] Humans can control and precisely vary the collapse rate of electrons using a scanning tunneling microscope.

[48] See (Bassi & Ulbricht, 2014); (Ghirardi, 2004, p. 406).

4.4. Quantum State Localization

The Bell Identity links the collapse of a quantum state to the simultaneous reduction in the number of Bell Spheres that comprise its Bell Point in the Planck Dimension and its Bell Field in 4D spacetime. Since this reduction must be to a subset of the Bell Spheres that comprised the quantum state prior to collapse, the Bell Identity places a strict boundary on the collapse outcome. Following the collapse of a Bell Point, a quantum state's Bell Field cannot be generally localized anywhere in the universe. It must be generally localized to a subset of its Bell Spheres prior to collapse, yielding a discrete spatial configuration consistent with observed quantum measurements.[49]

Although the Bell Identity places strict boundaries on the generalized location of a quantum state, it does not set a specific size for a quantum state's Bell Field in 4D spacetime following collapse. The generalized location may be related to the physical trigger that initiated collapse in the first instance or may vary based on the physical composition of the quantum state. In addition, high or low-energy collapses may have different localization characteristics, and a quantum state's momentum in 4D spacetime may also affect its localization.

4.5. Time and Instantaneous Collapse

Neither the Planck Dimension nor 4D spacetime independently supports the concept of instantaneous collapse. The Planck Dimension lacks a time dimension and, aside from collapse, does not support dynamic movement. In contrast, 4D spacetime has dynamic movement and a time dimension constrained by SR. Since the collapse of a Bell Point is instantaneous, it is mirrored in the three spatial dimensions of 4D spacetime, with no movement along the time dimension.

When a Physical Interaction in 4D spacetime initiates collapse, it directly affects the quantum state's Bell Point in the Planck Dimension, where SR constraints do not apply. Consequently, the Bell Point's collapse is instantaneous since it occurs in a context without time, space, volume, or the physical laws of 4D spacetime. The Bell Identity then ensures that the collapse of the Bell Spheres in the Planck Dimension is mirrored instantly in the reduction of Bell Spheres comprising the quantum state's Bell Field in 4D spacetime.

4.6. Quantum Tunneling

Though commonly described as 'quantum tunneling,' the appearance of a quantum state on the opposite side of a classically impenetrable barrier does not involve quantum tunneling

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[49] The D.O. model conflicts with mathematical models that describe quantum state collapse to a single dimensionless point, a Dirac delta function, or an eigenstate of position with a single discrete value.

in 4D spacetime. In many traditional interpretations, the probability of a quantum state appearing on the other side of an impenetrable barrier is based on the Schrödinger equation and the exponential decay of the quantum state's wave function within the barrier. Under the D.O. model, this event is caused by the instantaneous collapse of the quantum state's Bell Point in the Planck Dimension. When the Bell Spheres comprising a quantum state's Bell Point undergo instantaneous reduction, the Bell Identity ensures a one-to-one reduction in the number of Bell Spheres that constitute the quantum state's new Bell Field in 4D spacetime. Although the quantum state appears localized on the other side of the barrier, it does not "tunnel" through, and the laws of SR are not violated.[50]

4.7. The Born Rule Revisited

The D.O. model diverges fundamentally from the Born Rule and its probability density interpretation of wave-function collapse for continuous variables.[51] Unlike the Born Rule, the D.O. model asserts that a quantum state cannot appear instantaneously anywhere in 4D spacetime following its collapse. Instead, collapse is restricted to a discrete subset of the Bell Spheres occupied by the quantum state prior to collapse. Accordingly, rather than integrating a density function of the quantum state over a continuous space, the likelihood of generally locating a quantum state in a discrete, constrained space is a probability based on the square modulus of the quantum state's wave function.[52] For example, in the case of quantum tunneling, the collapse of a quantum state on the opposite side of a classically impenetrable barrier is a probability event, not a probability density.[53]

5. Resolving the Tension Between SR and Quantum Mechanics

The apparent incompatibility between SR and QM is often framed by terms and concepts derived from 4D spacetime rather than the Planck Dimension or the D.O. framework. Despite their usefulness in a closed 4D spacetime, common terms such as space-like separated, non-separability, entangled, instantaneous, local, non-local, as well as complex concepts like the relativity of simultaneity and relativistic energy increase, have unintentionally magnified a theoretical and experimental conflict that does not exist in the D.O. framework.[54]

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[50] See generally (Allori et al., 2021).

[51] See (Bacciagaluppi & Valentini, 2009, p. 136) regarding the debates between Schrödinger and Born on the probability density rule.

[52] Under the D.O. model, the probability of finding the location of a quantum state in a generalized location must be one.

[53] Although the D.O. model presents quantum state collapse as a probability rather than a probability density, it leaves unanswered whether a fully deterministic approach to quantum mechanics is possible. See (Hossenfelder & Palmer, 2020).

[54] The terminology that describes 4D spacetime may confirm Ludwig Wittgenstein's idea that language limits our perception of reality and thought. (Wittgenstein, 1922, p. 74).

5.1. Space-Like Separated

The term space-like separated is based upon a 4D spacetime structure composed of three dimensions of space and one dimension of time. The term is directly related to the concepts of space and time, the theory of SR, and the spatial distance between two or more events outside of one another's light cones. Nevertheless, the term loses meaning in relation to an ultra-high dimensional Bell Point where time, space, and volume do not exist.

5.2. Non-separability

Einstein was among the first to raise concerns regarding separability in theoretical physics. His primary concern related to two assumptions underlying his argument for incompleteness: that spatially separated systems are ontic states and that physical effects in space-like separated quantum systems cannot propagate faster than light.[55]

In 4D spacetime, a singlet state along the z-axis $\psi = \frac{1}{\sqrt{2}} (\uparrow z_1 \downarrow z_2 - \downarrow z_1 \uparrow z_2)$ is non-separable, although it is often considered an abstract mathematical concept. A non-separable singlet state has three key attributes: 1) spatial separation of the z_1 and z_2 states, 2) temporal separation of the z_1 and z_2 states, and 3) the existence of a single system.[56]

In the Planck Dimension, without time, space, or volume, a Bell Point exists as a single, non-separable entity.[57] The Bell Point is mirrored via the Bell Identity to the Bell Spheres that form the quantum state's Bell Field(s) in 4D spacetime. Although non-separability raises theoretical concerns within 4D spacetime, the non-separability of a Bell Point in the Planck Dimension does not violate SR. Instead, it reinforces the Dual Ontology's integrated structure, emphasizing the Bell Identity as an explanatory tool that links a quantum state's Bell Field(s) in 4D spacetime to its Bell Point in the Planck Dimension.[58]

5.3. Instantaneous, Superluminal, and Faster than Light

In QM, the terms *instantaneous*, *superluminal,* and *faster than light* often describe the collapse of a quantum state in 4D spacetime. Following the collapse of a quantum state, the terms instantaneous, superluminal, and faster than light are typically used to describe the

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[55] Einstein's primary concern was not with non-separability per se but with the possibility that non-separability implied a violation of his theory of special relativity. (Howard, 1985, pp. 172-173); (Howard, 1989, p. 232). See also (Maudlin, 2011, pp. 88-89).

[56] See Note 55.

[57] See also (Ney, 2016, 2021).

[58] The non-separability of a Bell Point addresses a concern raised by Einstein. Einstein questioned whether spatially separated quantum states in 4D spacetime had an independent reality. (Wiseman, 2006). The existence of a single ultra-high dimensional Bell Point would help to prove two points. First, space-like quantum states separated in 4D spacetime are ontic, and second, they are not physically independent.

quantum state's role in 1) communication, 2) signaling or the absence of signaling, 3) information transmission, and 4) matter and energy transfer.

Under the D.O. model, however, the terms describe the physical collapse of a Bell Point in the Planck Dimension rather than a collapse in 4D spacetime. Following the collapse, the reduction in the number of Bell Spheres that comprise a quantum state's Bell Point in the Planck Dimension is simultaneously mirrored by a reduction in the Bell Spheres that comprise the quantum state's generally localized Bell Field in 4D spacetime. The process is instantaneous, but SR has not been violated.

5.4. The Quantum Connection

In 4D spacetime, quantum discrimination describes a quantum state's ability to maintain an exclusive connection to the exclusion of all other quantum states, and unattenuated denotes the strength (or non-attenuation) of a quantum state's connection.[59] The terms are typically used to denote the connection between space-like separated entangled states in 4D spacetime. Moreover, discrimination and non-attenuation imply an instantaneous and continuous connection that violates the maximum speed of light.

In the context of the D.O., quantum discrimination and non-attenuation are directly related to the Bell Identity and the one-to-one identity and mapping between each of the Bell Spheres that comprise a quantum state's Bell Field(s) in 4D spacetime and its Bell Point in the Planck Dimension. There is nothing in either the structure of the D.O. or in the dynamics of a quantum state's spreading or collapse that suggests that the ability to discriminate or the lack of attenuation implies a violation of Einstein's theory of SR. On the contrary, the D.O. model explains why a quantum state's ability to discriminate and its non-attenuation are physical phenomena that do not violate SR.[60]

5.5. Bell's Theorem, Locality and Non-locality

John Bell's inequality theorem marks one of the most significant developments in quantum theory during the latter half of the 20th century.[61] The inequality theorem asserts that relativistic local causation theories cannot account for the statistical predictions of quantum mechanics in spin experiments of entangled states in the singlet state.[62] More broadly, Bell's

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[59] See (Maudlin, 2011, pp. 21-2).

[60] The ability of a Bell Point to maintain a quantum connection also answers the self-interference puzzle outlined in (Gao, 2020). An electron's Bell Point contains all of the information regarding an electron's charge distribution regardless of whether the electron is space-like separated in 4D spacetime. The electron's Bell Point also quantum discriminates and is non-attenuated, but it does not interfere with itself. In this sense, all electrons (and all quantum states) are not the same; they are all different. See also (Sebens, 2021, 2023); (Wechsler, 2021).

[61] (Brunner et al., 2014); (Norsen, 2011).

[62] (Goldstein et al., 2011); (Maudlin, 2014, p. 21); See also (Bell & Gao, 2016).

theorem indicates that any theory conforming to the results of quantum experiments cannot be local.[63] [64]

While the local vs. non-local causality debate is central to quantum theories that assume a closed 4D spacetime, concepts of time, space, or volume do not apply in the Planck Dimension. In the Planck Dimension, a quantum state's Bell Point is not separable, nor is it space-like separated. Accordingly, the D.O. framework shifts the local vs. non-local causality discussion without challenging Bell's inequality theorem.

Nevertheless, the D.O. model reframes quantum state collapse, presenting it as an external event to 4D spacetime rather than evidence of non-local causality. This approach strengthens Bell's theorem by describing quantum state collapse as a physical event beyond 4D spacetime. Rather than invoking a problematic non-local event, the collapse of a Bell Point in the Planck Dimension and the generalized localization of a quantum state in 4D spacetime bypasses the non-locality issue.[65]

5.6. The Relativity of Simultaneity

The historical tension between SR and QM extends to Einstein's relativity of simultaneity. SR holds that 1) all inertial reference frames (frames moving at constant speed relative to one another) are equally valid, and 2) the speed of light in a vacuum is invariant for all observers in these frames. Consequently, the relativity of simultaneity posits that 1) whether two spatially separated events occur simultaneously depends on the observer's frame of reference, and 2) observers in different frames may conclude that the same event happened at different times.

In the case of space-like separated entangled electrons in the singlet state in the z-axis $\psi = \frac{1}{\sqrt{2}}(\uparrow z_1 \downarrow z_2 - \downarrow z_1 \uparrow z_2)$, an experiment collapsing the z_1 electron also causes the simultaneous collapse of the z_2 electron. Since the relativity of simultaneity theory suggests that the order of the cause (the collapse of z_1) and effect (the collapse of z_2) depends on the observer’s frame of reference, the simultaneous collapse seemingly challenges SR, implying a violation of Lorentz Invariance and a preferred frame of reference.[66]

The D.O. model resolves this by framing quantum state collapse as an event external to 4D spacetime. For a quantum state in the singlet state in the z-axis, it is immaterial whether the experiment in 4D spacetime is conducted on z_1 or z_2 first or whether the quantum state is space-like separated. The Bell Identity ensures that an experiment on either quantum state in

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[63] Although the precise interpretations of locality and non-locality are complex and extensively debated, these definitions lie beyond the scope of this analysis. Here, the terms local and non-local are causal concepts associated with 4D spacetime and the maximum speed of light. See (Ney, 2021, p. 96); (Allori, 2022).

[64] See (Maudlin, 2011, p. 53, Note 1).

[65] See (Allori, 2023).

[66] (Maudlin, 2011, p. 185).

4D spacetime is simultaneously conducted on the quantum state's single Bell Point in the Planck Dimension. Moreover, the Bell Identity simultaneously reflects the instantaneous collapse of the Bell Spheres in the Planck Dimension as a reduction in the Bell Spheres comprising the now generally localized Bell Fields of both z_1 and z_2 in 4D spacetime. The formerly entangled quantum state now forms a product state. While the collapse was instantaneous and simultaneous, the 4D spacetime laws of SR have not been violated.

5.7. Relativistic Energy Increase

The instantaneous nature of quantum state collapse appears to challenge Einstein's relativistic energy increase theory. The theory posits that the relativistic energy of a body moving relative to an observer increases as its velocity accelerates. As an object approaches the speed of light, its relativistic kinetic energy theoretically approaches infinity, though SR limits its speed. In quantum mechanics, momentum is typically used instead of velocity; accordingly, as a quantum state's momentum increases, so does its associated energy. To reach or exceed the speed of light, as in the case of instantaneous collapse, the energy required would be infinite.

While the collapse of a quantum state's Bell Point is instantaneous, it occurs as a physical event external to 4D spacetime. The D.O. model and the Bell Identity ensure that the instantaneous collapse results in a reduction in the number of Bell Spheres comprising the quantum state's Bell Point and Bell Field(s). Consequently, the reduction in Bell Spheres in the Bell Field is also instantaneous. However, the process does not result in a relativistic energy increase of the quantum state in either 4D spacetime or the Planck Dimension.

6. Experimental Considerations

The D.O. model introduces several theoretical conclusions that deviate from both the Standard Model and other quantum theories. While other interpretations rely on abstract structures to address the question of relativistic energy increase, the D.O. model proposes a physical basis for the absence of such an increase following the instantaneous collapse of a quantum state in the Planck Dimension. Since the dynamic evolution and acceleration of quantum states in 4D spacetime are constrained by SR, but collapse occurs instantaneously in the Planck Dimension, where SR does not apply, an experiment measuring the absence of relativistic energy increase at the moment of collapse could support the D.O. model's prediction that collapse is external to 4D spacetime.

Additional experimental tests could further examine the D.O. model's explanatory depth by testing predictions that 1) quantum state collapse is governed by a probability, not a probability density; 2) a quantum state collapses to a subset of the Bell Spheres comprising the state immediately before collapse; 3) quantum states lack spatially extended tails in 4D spacetime; 4) quantum tunneling reflects an instantaneous collapse in the Planck Dimension rather than tunneling across an impassible barrier in 4D spacetime; 5) quantum states, rather than particles, fundamentally represent subatomic entities; and 6) quantum jumps are best understood as quantum collapses rather than probabilistic jumps.

One additional test that supports the existence of an ontic Planck Dimension is the D.O. prediction that subatomic particles are not identical; they are unique. Such a test would indirectly support the existence of the D.O. ontological framework.[67]

7. Conclusion

The D.O. model's explanatory depth is based on a novel physical and dynamic approach that resolves the SR-QM tension in a way that previous frameworks have not achieved. Built on a substructure of Discrete Spheres and the SOAN, the D.O.'s integrated ((3 x N) + 3) structure replaces GR's continuous 4D spacetime manifold with a discrete, curved 4D spacetime and substitutes abstract mathematical spaces with a physical, ultra-high-dimensional (3 x N) Planck Dimension. Consequently, the model supports the dynamic evolution of single and N-body quantum states in discrete 4D spacetime, in full compliance with SR, while permitting the instantaneous collapse of quantum states in the Planck Dimension, where SR constraints do not apply.

Unlike theories that rely on ad hoc assumptions, fine-tuning, or perturbative techniques, the D.O. framework presents a unified ontological, theoretical, and mathematical approach capable of comprehensively addressing the SR-QM tension and reshaping fundamental assumptions about SR and QM integration. Diverging from other quantum theories, the model reinterprets quantum phenomena by establishing new foundations for understanding the physical nature of quantum states, nonlocality, entanglement, space-like separation, and non-separability.

Additionally, the model reinterprets fundamental concepts such as indeterminism, generalized localization, quantum non-attenuation, quantum exclusivity, the relativity of simultaneity, and relativistic energy increase. The D.O. model provides consistent alternative explanations for several thought experiments, including the Einstein/de Broglie Boxes, double-slit, which-way, and Bohm-EPR experiments, with the added benefit of applying physical laws uniformly across single and N-body quantum states. Moreover, the model redefines the Born Rule's probability density as a probability, replaces 4D quantum tunneling with Bell Point collapse, and explains collapse triggers as localized physical interactions governed by fundamental forces in 4D spacetime.

The D.O. model introduces new mathematical formalisms aligned with its ontology and dynamics, aimed at describing physical phenomena without imposing constraints on the underlying framework. By replacing traditional constructs like the Schrödinger equation,

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[67] See Note 60.

Hilbert and Fock spaces, and quantum mechanical operators, it supports a nonlinear evolution of quantum states in 4D spacetime and instantaneous collapse in the Planck Dimension, in line with GR's dynamics, background independence, and SR's physical laws. Despite these novel interpretations, the D.O. model uniquely preserves GR's causal structure, making it a fully GR-compliant quantum framework.

Serving as the cornerstone of the D.O. model's explanatory depth, the SOAN provides an ontic foundation essential to addressing the SR-QM tension. Unlike abstract constructs, the SOAN grounds the framework in a state of "nothingness" that is physically meaningful and distinct from the traditional void or absence. The ontic nature of the SOAN allows the D.O. model to establish coherent, physically grounded relationships across 4D spacetime and the Planck Dimension, making it an indispensable component of the model's unified approach.

Finally, the D.O. model's implications extend beyond unifying SR and QM. Part II explores the model's explanatory depth with regard to the GR-QG tension, addressing complex issues such as singularities, renormalization, nonlocality, entanglement, gravity, time, and the black hole information paradox. The analysis also examines the arrow of time and the emergence of a homogeneous, isotropic 4D spacetime at t = 0, offering a cohesive framework for understanding foundational questions in both relativity and quantum gravity.[68]

Acknowledgments:

This analysis benefited immeasurably from lengthy and vigorous debates and penetrating criticism from Dr. Stanley Kahan and Mr. Joseph Atsmon. Over many years, Dr. Kahan's intuitive insights and Mr. Atsmon's analytical probing not only helped shape the analysis but also explored all of its fundamental topics, from the nature of the SOAN and the Planck Dimension and their relationship to 4D spacetime and quantum mechanics to the collapse of quantum states in the Planck Dimension. I still cannot thank them enough. Once again, I would also like to express a special thanks to Ms. Naomi Kahan for her patience and technical expertise in preparing this manuscript.

Appendix A - Mathematical Formalisms

The following mathematical formalisms are based upon the ontological structure and fully integrated dynamics of the D.O.'s unified ((3 x N) + 3) structure. SR governs the dynamic evolution of all single and N-body quantum states' Bell Field(s) in a discrete 4D spacetime but is not applicable to the instantaneous collapse of all single and N-body quantum states' Bell Points in the Planck Dimension. A discrete Quantum Field Theory on Curved Spacetime

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[68] For an early version of Part II, see (Kahan, 2024b, pp. 24-29).

ensures compatibility with GR and background independence.

1. Special Relativity

Einstein's theory of SR is modified to conform with a discrete 4D spacetime.

1.1 Discrete Maxwell Equations

Purpose:

Maxwell's equations use discrete differential equations to describe electric and magnetic fields for Discrete Spheres in 4D spacetime.

Equations:

A. Gauss's Law for Electricity:

$$\nabla \cdot \boldsymbol{E}_{ijkl} = \frac{\boldsymbol{\rho}_{ijkl}}{\boldsymbol{\epsilon}_{0}}$$

B. Gauss's Law for Magnetism:

$$\nabla \cdot \boldsymbol{B}_{ijkl} = \boldsymbol{0}$$

C. Faraday's Law of Induction:

$$\nabla \times \boldsymbol{E}_{ijkl} = -\frac{\partial \boldsymbol{B}_{ijkl}}{\partial \boldsymbol{t}}$$

D. Ampère’s Law (with Maxwell’s correction):

$$\nabla \times \boldsymbol{B}_{ijkl} = \mu_0 \boldsymbol{J}_{ijkl} + \mu_0 \epsilon_0 \frac{\partial \boldsymbol{E}_{ijkl}}{\partial \boldsymbol{t}}$$

1.2 Discrete Dirac Equation

Purpose:

The Dirac equation uses discrete spinor fields and gamma matrices to describe fermion behavior, including spin and relativistic fields.

Equation:

$$\boldsymbol{i\gamma^{0}} \frac{\boldsymbol{\psi_{i,j+1} - \psi_{i,j}}}{\boldsymbol{\Delta t}} + \boldsymbol{i} \sum_{\boldsymbol{k=1}}^{\boldsymbol{3}} \boldsymbol{\gamma^{k}} \frac{\boldsymbol{\psi_{i+k,j} - \psi_{i-k,j}}}{\boldsymbol{2\Delta x}} - \boldsymbol{m\psi_{i,j}} = \boldsymbol{0}$$

The equation for an N-body quantum state:

$$i\hbar\frac{\partial\Psi_n(t)}{\partial t}=\sum_{j=1}^{N}\left(c\alpha_j\Delta_j+\beta_j m_j c^2\right)\Psi_n(t)$$

1.3 Discrete Klein-Gordon Equation

Purpose:

The Klein-Gordon equation uses second-order differential equations to model spin-0 particles in a relativistic context and to describe scalar field evolution.

Equation:

$$\frac{\phi_{i+1,j}-2\phi_{i,j}+\phi_{i-1,j}}{\Delta x^2}+\frac{\phi_{i,j+1}-2\phi_{i,j}+\phi_{i,j-1}}{\Delta t^2}+m^2\phi_{i,j}=0$$

The equation for an N-body quantum state:

$$\sum_{n=1}^{N}\left(\frac{\phi_{i_n+1,j}-2\phi_{i_n,j}+\phi_{i_n-1,j}}{\Delta x^2}+\frac{\phi_{i_n,j+1}-2\phi_{i_n,j}+\phi_{i_n,j-1}}{\Delta t^2}+m^2\phi_{i_n,j}\right)=0$$

2. General Relativity

The laws of GR are predicated on a continuous differentiable 4D spacetime manifold. Accordingly, the following equations integrate GR within the context of the D.O.'s discrete 4D spacetime.

2.1 Modified Regge Calculus for a Discrete 4D Spacetime

Purpose:

The Modified Regge calculus describes GR's spacetime curvature within the D.O.'s discrete Discrete Sphere framework. In this context, spacetime is composed of Discrete Spheres rather than a continuous manifold. Deficit angles at each Discrete Sphere represent the curvature of 4D spacetime.

Equation:

$$\sum_{\text{Discrete Spheres}} V_{\text{PS}}\delta_{\text{PS}}+\Lambda V_{\text{PS}}=2\kappa\sum_{\text{Discrete Spheres}} T_{\text{PS}}+\rho\Lambda V_{\text{PS}}$$

2.2 Discrete Einstein Field Equations

Purpose:

The discretization of Einstein's Field Equations describes how mass and energy influence the curvature of discrete spacetime.

Equation:

$$\sum_j V_j \delta_j = 2\kappa \sum_j T_j V_j$$

2.3 Modified Dirac Equation for Curved Discrete 4D Spacetime:

Purpose:

The Dirac equation has been modified for a curved spacetime in a discrete 4D spacetime framework to ensure accurate descriptions of fermionic fields in a relativistic context.

Equation:

$$\boldsymbol{i\gamma^{\mu} D_{\mu} \psi - m\psi = 0}$$

The equation for an N-body quantum state:

$$\sum_{n=1}^{N} \left(i\gamma^{0} \frac{\psi_{i_n,j+1} - \psi_{i_n,j}}{\Delta t} + i \sum_{k=1}^{3} \gamma^{k} \frac{\psi_{i_n+k,j} - \psi_{i_n-k,j}}{2\Delta x} - m\psi_{i_n,j} \right) = 0$$

2.4 Modified Klein-Gordon Equation for Curved Discrete 4D Spacetime:

Purpose:

The Klein-Gordon equation has been modified for curved spacetime in a discrete 4D spacetime framework to ensure spin-0 particles are properly modeled in a relativistic context.

$$\sum_{\mu,\nu} g_{i,j}^{\mu\nu} \left(\frac{\phi_{i+\hat{\mu},j} - 2\phi_{i,j} + \phi_{i-\hat{\mu},j}}{\Delta x^2} + \frac{\phi_{i,j+\hat{\nu}} - 2\phi_{i,j} + \phi_{i,j-\hat{\nu}}}{\Delta t^2} \right) + \frac{m^2 c^2}{\hbar^2} \phi_{i,j} = 0$$

The equation for an N-body quantum state:

$$\sum_{k=1}^{N}\left(\sum_{\mu,\nu} g_{i,j,k}^{\mu\nu}\left(\frac{\phi_{i+\hat{\mu},j,k} - 2\phi_{i,j,k} + \phi_{i-\hat{\mu},j,k}}{\Delta x^2} + \frac{\phi_{i,j+\hat{\nu},k} - 2\phi_{i,j,k} + \phi_{i,j-\hat{\nu},k}}{\Delta t^2}\right) + \frac{m_k^2 c^2}{\hbar^2}\phi_{i,j,k}\right) = 0$$

3. Dynamic Evolution of Single and N-Body Quantum States in 4D Spacetime

Purpose:

The dynamic evolution of single and N-body quantum states in a discrete 4D spacetime and the Bell Identity's continuous mapping of quantum states in 4D spacetime and the Planck Dimension ensures quantum coherence and unitarity. Changes in a quantum state's Bell Field(s) in 4D spacetime are instantaneously mirrored by corresponding changes in the quantum state's single Bell Point in the Planck Dimension.

3.1 General Law of Quantum State Evolution under the D.O. Model

Equations:

$$DE\colon \phi_{i,n}^{\mathrm{4D}} \leftrightarrow \text{Bell Identity } \psi_n^{\mathrm{PS}}$$

$$\delta\phi_{i,n}^{\mathrm{4D}} = \left(\phi_{i,n}^{\mathrm{4D}}, \phi_{i,n+1}^{\mathrm{4D}}, \dots, t\right)$$

$$\delta\psi_n^{\mathrm{PS}} = \left(\psi_n^{\mathrm{PS}}, \psi_{n+1}^{\mathrm{PS}}, \dots, t\right)$$

Dynamic Process:

$$DE\colon \left(\phi_{i,n}^{1,\mathrm{4D}}, \phi_{i,n}^{2,\mathrm{4D}}, \dots\right) \leftrightarrow \text{Bell Identity } \psi_n^{\mathrm{PS}}$$

$$DE\colon \left(\phi_{i,n}^{A,\mathrm{4D}}, \phi_{i,n}^{B,\mathrm{4D}}, \dots\right) \leftrightarrow \text{Bell Identity } \psi_n^{\mathrm{PS}}$$

Definitions:

DE: The dynamic evolution of single or N-body quantum state in 4D spacetime.

Bell Identity: The one-to-one identity and mapping between a Bell Sphere in 4D spacetime and the Planck Dimension. The same Bell Spheres that form a quantum state's Bell Field(s) in 4D spacetime and also form its single Bell Point in the Planck Dimension.

(i): Time variable in 4D spacetime.

(n): The number of Bell Fields that comprise a quantum state in 4D spacetime.

$\left(\boldsymbol{\phi}_{i,n}^{\mathbf{4D}}\right)$**:** Represents the number of Bell Fields that comprise a single or N-body quantum state at any given moment of time in 4D spacetime.

$\left(\boldsymbol{\phi}_{i}^{\mathbf{1,4D}}\right)$: Represents Bell Field 1 in connection with a single body quantum state at any given moment in time in 4D spacetime.

$\left(\boldsymbol{\phi}_{i}^{\mathbf{2,4D}}\right)$: Represents Bell Field 2 in connection with a single body quantum state at any given moment in time in 4D spacetime.

$\left(\boldsymbol{\phi}_{i}^{\mathbf{A,4D}}\right)$**:** Represents Bell Field A in connection with an N-body quantum state in 4D spacetime

$\left(\boldsymbol{\phi}_{i}^{\mathbf{B,4D}}\right)$**:** Represents Bell Field B in connection with an N-body quantum state in 4D spacetime.

$(\boldsymbol{\psi}^{\mathbf{PS}})$**:** Represents a single or N-body quantum state's single Bell Point in the Planck Dimension.

3.2 General Law of Single Quantum State Evolution Under the D.O. Model

Equation:

$$\boldsymbol{DE}: \boldsymbol{\phi}_{i}^{\mathbf{4D}} \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}^{\mathbf{PS}}$$

Dynamic Process

$$\boldsymbol{DE}: \left(\boldsymbol{\phi}_{i}^{\mathbf{1,4D}}, \boldsymbol{\phi}_{i}^{\mathbf{2,4D}}, \dots\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}^{\mathbf{PS}}$$

3.3 General Law of N-body Quantum State Evolution Under The D.O. Model

Equation:

$$\boldsymbol{DE}: \left(\boldsymbol{\phi}_{i}^{\boldsymbol{A},\mathbf{4D}}, \boldsymbol{\phi}_{i}^{\boldsymbol{B},\mathbf{4D}}, \dots\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}^{\mathbf{PS}}$$

Dynamic Process**:**

$$\boldsymbol{DE}: \left(\boldsymbol{\phi}_{i}^{\boldsymbol{A},\mathbf{4D}}, \boldsymbol{\phi}_{i}^{\boldsymbol{B},\mathbf{4D}}, \dots\right) \rightarrow \left(\boldsymbol{\phi}_{\boldsymbol{i+1}}^{\boldsymbol{A},\mathbf{4D}}, \boldsymbol{\phi}_{\boldsymbol{i+1}}^{\boldsymbol{B},\mathbf{4D}}, \dots\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}_{\boldsymbol{i+1}}^{\mathbf{PS}}$$

3.4 Dynamic Evolution – Bohm/EPR Experiment Under The D.O. Model

Equation:

$$\boldsymbol{DE}\colon \left(\boldsymbol{\phi}_{\boldsymbol{i}}^{\boldsymbol{A},\mathbf{4D}}, \boldsymbol{\phi}_{\boldsymbol{i}}^{\boldsymbol{B},\mathbf{4D}}\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}^{\mathbf{PS}}$$

Dynamic Process:

$$\boldsymbol{DE}\colon \left(\boldsymbol{\phi}_{\boldsymbol{i}}^{\boldsymbol{A},\mathbf{4D}}, \boldsymbol{\phi}_{\boldsymbol{i}}^{\boldsymbol{B},\mathbf{4D}}\right) \to \left(\boldsymbol{\phi}_{\boldsymbol{i+1}}^{\boldsymbol{A},\mathbf{4D}}, \boldsymbol{\phi}_{\boldsymbol{i+1}}^{\boldsymbol{B},\mathbf{4D}}\right) \leftrightarrow \textbf{Bell Identity } \boldsymbol{\psi}_{\boldsymbol{i+1}}^{\mathbf{PS}}$$

4. The Planck Dimension Collapse Operator

Purpose:

Section 4 of the mathematical formalism addresses the physical mechanisms underlying the instantaneous collapse of all single and N-body quantum states' single Bell Point within the D.O.'s unified ((3 x N) + 3) structure and the simultaneous reduction in the number of Discrete Sphere's that form all quantum state's new Bell Field(s) in 4D spacetime.

4.1 General Law of Quantum State Collapse Under The D.O. Model

Equations:

$$\boldsymbol{C}\colon \boldsymbol{\psi}_{\boldsymbol{j}}^{\mathbf{PS}} \leftrightarrow \textbf{Bell Identity } \boldsymbol{\phi}_{\boldsymbol{i,j}}^{\mathbf{4D}}$$

$$\boldsymbol{\delta}\left(\boldsymbol{\psi}_{\boldsymbol{j}}^{\mathbf{PS}} - \boldsymbol{\psi}_{\boldsymbol{j'}}^{\mathbf{PS}}\right)$$

$$\boldsymbol{\delta}\left(\boldsymbol{\phi}_{\boldsymbol{i,j}}^{\boldsymbol{4D}} - \boldsymbol{\phi}_{\boldsymbol{i,j'}}^{\boldsymbol{4D}}\right)$$

Collapse Process:

$$\boldsymbol{T} \to \boldsymbol{\psi}_{\boldsymbol{j}}^{\mathbf{PS}} \to \boldsymbol{\psi}_{\boldsymbol{j'}}^{\mathbf{PS}} \to \left(\boldsymbol{\phi}_{\boldsymbol{i,j'}}^{\mathbf{4D}}\right)$$

$$\boldsymbol{T} \to \boldsymbol{\psi}_{\boldsymbol{j}}^{\mathbf{PS}} \to \boldsymbol{\psi}_{\boldsymbol{j'}}^{\mathbf{PS}} \to \left(\boldsymbol{\phi}_{\boldsymbol{i,j'}}^{\mathbf{4D}}\right)$$

$$\boldsymbol{T} \to \boldsymbol{\psi}_{\boldsymbol{j}}^{\mathbf{PS}} \to \left(\boldsymbol{\psi}_{\boldsymbol{j'_1}}^{\mathbf{PS}}, \boldsymbol{\psi}_{\boldsymbol{j'_2}}^{\mathbf{PS}}, \dots, \boldsymbol{\psi}_{\boldsymbol{j'_N}}^{\mathbf{PS}}\right) \to \left(\boldsymbol{\phi}_{\boldsymbol{i,j'_1}}^{\mathbf{4D}}, \boldsymbol{\phi}_{\boldsymbol{i,j'_2}}^{\mathbf{4D}}, \dots, \boldsymbol{\phi}_{\boldsymbol{i,j'_N}}^{\mathbf{4D}}\right)$$

Definitions:

C: The collapse operator describes the process initiated by a 4D spacetime trigger that leads to the instantaneous collapse of a single or N-body quantum state's Bell Point in the Planck Dimension. Following the collapse:

A single quantum state will form a single Bell Point in the Planck Dimension and a single Bell Field in 4D spacetime.

An N-body quantum state will form multiple independent Bell Points in the Planck Dimension and multiple corresponding Bell Fields in 4D spacetime.

Each resulting Bell Point and corresponding Bell Field will be a subset of the original Bell Point and Bell Field(s).

The operator also reflects the effect of the Bell Identity, which ensures an instantaneous and simultaneous reduction in the number of Bell Spheres that comprise the single or N-body quantum state's new Bell Field(s) in 4D spacetime, causing the generalized localization of the new Bell Field(s).

T: The 4D spacetime trigger that initiates the collapse of the quantum state's Bell Point in the Planck Dimension.

Bell Identity: Ensures a one-to-one correspondence between the Bell Spheres that form a Bell Point in the Planck Dimension and one or more Bell Fields in 4D spacetime.

For a single quantum state, the Bell Identity ensures an instantaneous reduction in the number of Bell Spheres that form a single new Bell Point and Bell Field.

For an N-body quantum state, the Bell Identity ensures an instantaneous reduction in the number of Bell Spheres that form multiple Bell Points and corresponding Bell Fields.

$(\boldsymbol{\psi})$: The wave function of the quantum state.

$(\boldsymbol{j})$: Represents the initial number of Bell Spheres that comprise the quantum state before collapse.

$(\boldsymbol{j'})$: Represents the reduced number of Bell Spheres that comprise the quantum state after collapse.

$(\boldsymbol{i}\,)$: Time variable in 4D spacetime.

$(\boldsymbol{\phi})$ Represents the quantum state's Bell Field(s) in 4D spacetime.

(δ): Delta function indicating the change or difference.

(PS): the Planck Dimension

(4D): 4D spacetime

$(\boldsymbol{\psi}_{j}^{\mathbf{PS}})$: The quantum state before the collapse of its single Bell Point.

($\boldsymbol{\psi}^{\mathbf{PS}}_{\boldsymbol{j'}}$): The quantum state's collapsed state following the collapse of its Bell Point. Following the collapse, a single quantum state will form a single new Bell Point, and an N-body quantum state will form two or more new Bell Points. Each new Bell Point is a subset of the initial Bell Spheres that formerly comprised the quantum state's single Bell Point.

$\left(\boldsymbol{\phi}^{\boldsymbol{4D}}_{\boldsymbol{i,j}}\right)$: The quantum state's Bell Field in 4D spacetime before collapse.

$\left(\boldsymbol{\phi}^{\boldsymbol{4D}}_{\boldsymbol{i,j'}}\right)$: Following the collapse of the quantum state's Bell Point, a single quantum state will form a single new Bell Field in 4D spacetime, and an N-body quantum state will form two or more new Bell Fields in 4D spacetime. The new Bell Field(s) are generally localized in 4D spacetime and are subsets of the original Bell Fields that comprised the quantum state.

Delta Function *(δ):*

– The first delta function represents the precise reduction in the number of Bell Spheres that form one or more of the quantum state's Bell Points in the Planck Dimension following the quantum state's collapse.

– The second delta function indicates the identical reduction in the number of Bell Spheres that form one or more of the quantum state's Bell Fields in 4D spacetime following the generalized localization of the new Bell Field(s).

4.2 General Law of Single Quantum State Collapse Under The D.O. Model

Equation:

$$\boldsymbol{C}\colon \boldsymbol{\psi}^{\mathbf{PS}}_{\boldsymbol{j}} \leftrightarrow \textbf{Bell Identity}\ \boldsymbol{\varphi}^{\mathbf{4D}}_{\boldsymbol{i,j}}$$

$$\boldsymbol{\delta}\left(\boldsymbol{\psi}^{\mathbf{PS}}_{\boldsymbol{j}} - \boldsymbol{\psi}^{\mathbf{PS}}_{\boldsymbol{j'}}\right)$$

$$\boldsymbol{\delta}\left(\boldsymbol{\varphi}^{\mathbf{4D}}_{\boldsymbol{i,j}} - \boldsymbol{\varphi}^{\mathbf{4D}}_{\boldsymbol{i,j'}}\right)$$

Collapse Process:

$$\boldsymbol{T} \rightarrow \boldsymbol{\psi}^{\mathbf{PS}}_{\boldsymbol{j}} \rightarrow \boldsymbol{\psi}^{\mathbf{PS}}_{\boldsymbol{j'}} \rightarrow \left(\boldsymbol{\phi}^{\mathbf{4D}}_{\boldsymbol{i,j'}}\right)$$

4.3 General Law of N-Body Quantum State Collapse Under The D.O. Model

Equation:

$$\boldsymbol{C}\colon \boldsymbol{\psi}^{\mathbf{PS}}_{\boldsymbol{j}} \leftrightarrow \textbf{Bell Identity}\ \boldsymbol{\varphi}^{\mathbf{4D}}_{\boldsymbol{i,j}}$$

$$\boldsymbol{\delta}\left(\boldsymbol{\psi}^{\mathbf{PS}}_{\boldsymbol{j}} - \boldsymbol{\psi}^{\mathbf{PS}}_{\boldsymbol{j'}}\right)$$

$$\boldsymbol{\delta}\left(\boldsymbol{\varphi}^{\mathbf{4D}}_{\boldsymbol{i,j}} - \boldsymbol{\varphi}^{\mathbf{4D}}_{\boldsymbol{i,j'}}\right)$$

Collapse Process:

$$\boldsymbol{T} \rightarrow \boldsymbol{\psi}_{\boldsymbol{j}}^{\mathbf{PS}} \rightarrow \left(\boldsymbol{\psi}_{\boldsymbol{j}_1'}^{\mathbf{PS}}, \boldsymbol{\psi}_{\boldsymbol{j}_2'}^{\mathbf{PS}}, \dots, \boldsymbol{\psi}_{\boldsymbol{j}_N'}^{\mathbf{PS}}\right) \rightarrow \left(\boldsymbol{\Phi}_{\boldsymbol{i},\boldsymbol{j}_1'}^{\mathbf{4D}}, \boldsymbol{\Phi}_{\boldsymbol{i},\boldsymbol{j}_2'}^{\mathbf{4D}}, \dots, \boldsymbol{\Phi}_{\boldsymbol{i},\boldsymbol{j}_N'}^{\mathbf{4D}}\right)$$

4. Quantum State Collapse – Bohm/EPR Experiment Under The D.O. Model

Equation:

$$\boldsymbol{C}\colon \boldsymbol{\psi}_{\boldsymbol{AB}}^{\mathbf{PS}} \leftrightarrow \textbf{Bell Identity } \boldsymbol{\varphi}_{\boldsymbol{i},\boldsymbol{j}}^{\boldsymbol{A},\boldsymbol{B},\boldsymbol{4D}}$$

$$\boldsymbol{C}\colon \boldsymbol{\psi}_{\boldsymbol{AB}}^{\boldsymbol{PS}} \leftrightarrow \textbf{Bell Identity } \boldsymbol{\varphi}_{\boldsymbol{i},\boldsymbol{j}}^{\boldsymbol{A},\boldsymbol{B},\boldsymbol{4D}}$$

$$\boldsymbol{\delta}\left(\boldsymbol{\psi}_{\boldsymbol{AB}}^{\boldsymbol{PS}} - \boldsymbol{\psi}_{\boldsymbol{A'B'}}^{\boldsymbol{PS}}\right)$$

$$\boldsymbol{\delta}\left(\boldsymbol{\varphi}_{\boldsymbol{i},\boldsymbol{j}}^{\boldsymbol{A},\boldsymbol{B},\boldsymbol{4D}} - \boldsymbol{\varphi}_{\boldsymbol{i},\boldsymbol{j}}^{\boldsymbol{A'B'},\boldsymbol{4D}}\right)$$

Collapse Process:

$$\boldsymbol{T} \rightarrow \boldsymbol{\psi}_{\boldsymbol{AB}}^{\mathbf{PS}} \rightarrow \left(\boldsymbol{\psi}_{\boldsymbol{A'}}^{\mathbf{PS}}, \boldsymbol{\psi}_{\boldsymbol{B'}}^{\mathbf{PS}}\right) \rightarrow \left(\boldsymbol{\phi}_{\boldsymbol{i},\boldsymbol{j'}}^{\boldsymbol{A},\boldsymbol{4D}}, \boldsymbol{\phi}_{\boldsymbol{i},\boldsymbol{j'}}^{\boldsymbol{B},\boldsymbol{4D}}\right)$$

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