A Dimensional Theory of Quantum Mechanics

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Abstract

Ever since quantum mechanics was first developed, it has been unclear what it really tells us about reality. A novel framework, based on 5 axioms, is presented here which offers an interpretation of quantum mechanics unlike any considered thus far: It is postulated that physical objects can exist in one of two distinct modes, based on whether they have an intrinsic actual spacetime history or not. If they do, their mode of existence is actual and they can be described by classical physics. If they do not, then their mode of existence is called actualizable and they must be described in terms of an equal-weight superposition of all possible actualizable (not actual) histories.

The distinction is based on an axiom according to which there exists a limit in which spacetime reduces to a one-dimension reduced version, called areatime, and that objects which merely actualizably exist in spacetime actually exist in areatime. The operational comparison of the passage of time for such objects to the passage of time for a spacetime observer is postulated to be made possible by what is called an angular dual bilateral symmetry. This symmetry can be decomposed into the superposition of two imaginary phase angles of opposite sign. To mathematically describe the spacetime manifestation of objects which actually exist in areatime, each actualizable spacetime history is associated with an actualizable path, which in turn is associated with the imaginary phases. For a single free particle, the complex exponent is identified with a term proportional to its relativistic action, thus recovering the path integral formulation of quantum mechanics.

Although based on some highly unfamiliar ideas, this framework appears to render at least some of the usual mysteries connected with quantum mechanics amenable to simple conceptual understanding. It also appears to connect the foundations of quantum theory to the foundation of the special theory of relativity while clarifying its relationship to the general theory of relativity and yields a testable prediction about a type of experiment, as yet unperformed, which under the current paradigm is utterly unexpected, namely, that the gravitational field of radiation is zero. The paper concludes with some speculations about how the theory may be extended to a metatheory of nature.

Keywords: Dimensional Theory, Foundations of Quantum Mechanics, Actualizable Histories, Actualizable Mass, Areatime, Angular Dual Bilateral Symmetry, Emergence of Spacetime

Popular Summary: What does quantum mechanics really tell us about reality? This paper introduces a new theory which explains it as follows: what sets quantum objects apart from ordinary objects is that they have an altogether different mode of existence. Unlike actual objects familiar from our direct experience, quantum objects are missing something before they can become actual, and are therefore called actualizable. What they are missing is a spacetime history in their own frame, and as a result, observers must attribute to them all possible actualizable histories to describe them. They are missing a spacetime history because of a postulated limit in which spacetime reduces to a one-dimension lower version, called areatime; actualizable objects are the spacetime manifestation of objects which actually exist (and do have a history in their own frame) in areatime. A postulated symmetry of nature relates the passage of time for these objects to the passage of time for spacetime observers, but also gives such objects wavelike properties. The framework offers easy to understand explanations for some of the mysterious aspects of quantum

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mechanics, may be interpreted to directly connect quantum mechanics to Einstein's special theory of relativity and predicts that the gravitational field of radiation is zero. Speculatively, it may even be generalized to a 'theory of theories' of nature. Although it suggests answers to some open questions, it also raises several new ones.

1 Introduction

Ever since the theory of quantum mechanics was developed in its modern form in the mid 1920's, it has been plagued by a problem in regards to its interpretation. Its mathematical formalism, despite giving predictions in excellent agreement with accurate experiments, is evidently not sufficient to conclusively allow us to understand what the theory tells us about reality. This is in part due to the fact that at least the Hamiltonian formulation of quantum mechanics is based on mathematical, as opposed to physical, axioms and in greater part due to the fact that its predictions seem to collide with our everyday experience of reality. The Lagrangian (i.e. path integral) formulation partially remedies the first problem, but, being really the same theory, naturally also suffers from the second.

This paper presents a new framework which offers an interpretation of quantum mechanics unlike any considered thus far, but it does more than what previous interpretations of quantum mechanics have done. While, like previous interpretations, it suggests a particular way of thinking about what the usual mysteries connected with quantum mechanics tell us about reality, it may also connect the foundations of quantum theory to the foundations of the special theory of relativity while clarifying the relationship between quantum theory and the general theory of relativity. Unlike other interpretations, it gives a prediction about a type of experiment, as yet unperformed, which does not obviously follow from standard quantum mechanics and is under the current paradigm utterly unexpected (this justifies calling it a "theory"). Finally, it speculatively suggests a generalization that implies an altogether novel taxonomy of theories of nature. Parts of this framework had been introduced in recent previous papers [1, 2, 3], but, while based in large part on these works, this paper aims to present a self-contained description and also discuss the implications of what will be called the dimensional theory.

2 Building Up the Theory

The framework to be presented is based on 5 axioms, which will be introduced as the theory is developed in order to help the reader better understand how they fit together. As is in the nature of truly novel and unfamiliar ideas, some of these axioms may seem unusual at first, but hopefully once the presentation of the framework is complete, they will seem more intuitive.

It will be helpful to see where this framework will lead, so let us begin by presenting its main conclusion. In standard non-relativistic quantum mechanics, a system can be represented by a state vector $|\Psi>$ in Hilbert space which can be decomposed into (usually) an infinite number of basis vectors $|\psi_i>$. The 'measurement problem' refers to the fact that, under certain circumstances, namely when a 'measurement' is performed, the system is always found to be in a state described by one and only one of the basis vectors (in the basis that encompasses the possible outcomes of that particular measurement), rather than the superposition state (in that basis) predicted by Schrödinger's equation. Since the state vector can also be represented as a wavefunction Ψ, this is called the wave-function collapse [4]. We will see that according to the framework to be presented, the wave-function collapse can be represented as follows:

$$\Psi \xrightarrow{'Actualization'} \underline{\psi}_i \tag{1}$$

This differs from the standard representation in two important ways: First, the anthropocentric term 'measurement' has been replaced by the term 'actualization' to indicate an ontological transformation from the state immediately before the process to the one immediately thereafter. What is meant by this is that the two states differ in their *modes of existence*: The state before will be referred to as an 'actualizable' state and the state immediately thereafter as an 'actual' one, where 'actualizable' simply means 'capable of becoming actual'. This brings us to the second difference from the standard representation: To symbolically represent the actual state in quantum mechanics, it will be underlined. It is understood that an ordinary quantum system does not stay in the actual state $|\underline{\psi}_i>$ for long, as evidenced by the fact that soon after

the measurement it obeys Schrödinger's equation once again.
The question then becomes, what specifically is meant by this distinction? An analogy will help understand it better. Consider a point (x, y) in a 2-dimensional Euclidean plane as represented in fig. 1.

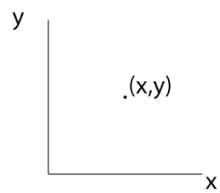

Figure 1: An arbitrary point in an xy-plane

If we wish to represent this point in Euclidean 3-space such that the x and y coordinates are the same as before, then we must depict it as an infinitely long line parallel to the z-axis, as shown in fig. 2.

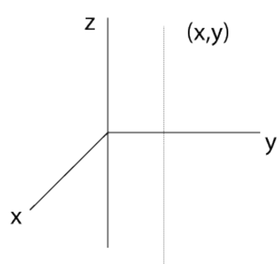

Figure 2: The same point in an xyz-space with the same xy coordinates as before now manifests itself as a superposition of an infinite number of *actualizable* points, one for each possible z-coordinate

This change in the representation of the point when moving from 2-space to 3-space occurs because it inherently 'lacks' any intrinsic property which can be associated with a z-coordinate. As a result, the point must be represented such that every z-value is included in its representation in 3-space as a realizable potentiality i.e. as a possible representation *if it were* an actual point in 3-space with that z-value. Put more suggestively, this line can be thought of as an *equal-weight superposition* i.e. a superposition equally contributed to by all the possible points in 3-space into any one of which the original point (x, y) can be transformed once it attains intrinsically a value for z. Note that for any *actual* point in 3-space, it is impossible to be characterized by two or more distinct z-values; distinct z values are *mutually incompatible* as properties of one and the same actual point in 3-space. The distinction between actual points in 3-space i.e. points which can be intrinsically characterized as (x, y, z), and the points in fig. 2 that constitute the infinite line which represents the point (x, y) in 3-space is exactly the kind of distinction that is referred to symbolically in equation (1), so let us call the latter *actualizable* points in 3-space. What is required to transform(x, y), an actual point in the plane but an infinite actualizable line in space, into an actual point in 3-space, then, is the acquisition of an intrinsic z-coordinate. This process can be schematically depicted as follows, with the understanding that referring to this process as 'actualization' implies here that after the process it actually exists in 3-space:

$$(x, y) \xrightarrow{\text{`}Actualization'} (x, y, z) \tag{2}$$

As a direct result of the actualization process, the superposition of an infinite number of actualizable points *collapses* to the actual point (x, y, z). By now it is hopefully evident that this is remarkably similar to the process described by equation (1). The analogy just presented, in conjunction with this conceptualization of the wave function collapse, suggests that quantum systems exist in a superposition of mutually incompatible states because they are actualizable manifestations of an entity or entities that intrinsically lack something until what we currently call a 'measurement' transforms them into an actual system. The axiom to be presented now specifies what is lacking. We will call this the *Principle of Actualizable Histories*:

Axiom I: *Any entity which lacks an intrinsic actual history in spacetime manifests itself in an equal-weight superposition of all possible actualizable histories associated with the spacetime objects into which it can be actualized* (3)

Here, an 'intrinsic actual history' is defined as a history experienced in a frame due to the passage of time, and by 'equal-weight superposition' it is meant that each intrinsic actual history has equal weight or importance in contributing to the spacetime manifestation of such an entity. At first glance, this axiom may seem rather strange. What entities could there be that 'lack an intrinsic actual history in spacetime'? It turns out that already special relativity provides one answer: Any entity that is associated with motion in space at speed c is also associated with zero proper time. A zero proper time means that no time is observed to pass for it by any spacetime observer; such entities are never observed to 'age'. This holds from the time they are observed to come into existence until they are observed to go out of existence. Thus, for the entire duration that they are observed to exist, in their proper frame no time passes. But the passage of time in a proper frame is by our definition precisely what is required to have an intrinsic actual history in spacetime. After all, this is how we defined an intrinsic actual history for any normal spacetime observer. It follows that any entity which is associated with motion in space at c lacks an intrinsic actual history in spacetime, and can therefore be considered to be subject to this axiom. The archetypical objects which are associated with this motion are photons, and photons are also known to be the epitome of quantum objects. However, photons are not the only types of quantum objects. Indeed, a formulation of non-relativistic quantum mechanics is only possible because there are systems which can be adequately described by quantum theory in regimes associated with motion in space much smaller than c. The property which makes this possible is what we call *mass*. But massive objects are associated with finite proper time, which means that they do not lack intrinsic actual histories.

How to address this problem? It is at this point that we need to introduce the novel fundamental distinction which will lie at the foundation of the distinction in equation (1): In order to avoid a contradiction when interpreting the superposition of quantum systems with which there is an associated mass in terms of the principle of actualizable histories, we must define a new concept, something that will be called *actualizable mass*. The idea behind this is that actualizable mass is to be thought of as the 'mass analog' of the actualizable points in fig. 2 which "look" like actual points in 3-space but aren't. More concretely, actualizable mass will be defined as a property of an object which seems like mass in the usual sense (now to be distinguished as 'actual mass'), particularly in the sense that it can be associated with motion in space $v < c$, even though only *retrospectively* [1], but is not associated with an intrinsic actual history. A particle with actualizable mass or no mass will be called an *actualizable particle*. Given this definition, we can introduce a preliminary version of the second axiom of this theory.

Axiom II (Preliminary Version):
There exist certain circumstances under which actualizable mass can be transformed to actual mass. (4)

This axiom is preliminary because it does not yet tell us under what circumstances this transformation takes place. That will be clarified after the third axiom is introduced, which provides the information that allows us to specify these circumstances. At this point, however, axiom II still allows us to represent the

[1]The qualification that only retrospectively one can associate motion $v < c$ with an actualizable particle is meant to save this definition from contradiction with special relativity: Clearly, if one could associate such motion, 'as it occurs', then there would have to be a passage of time by the familiar formula $\beta^2 + \gamma^{-1} = 1$ and therefore an intrinsic actual history associated with the particle. Notice that this way of associating motion is consistent with the empirical fact that we never directly observe superposed quantum particles in motion, but only deduce such motion after the fact (e.g. in the double slit experiment by the interference pattern), i.e. retrospectively.

fundamental process that underlies the wave function collapse for quantum systems with mass:

$$m \xrightarrow{'Actualization'} \underline{m} \tag{5}$$

It is important to note that what is here $\underline{m}$, the actual mass, corresponds to m in classical physics whereas the pre-actualization m, the actualizable mass, *has no classical analog.* That is because actualizable mass, by definition not being associated with an intrinsic actual history, belongs to 'massive' objects that by axiom I always exist in a superposition of actualizable histories. In order to minimize the change in notation required by the introduction of these novel concepts, one may skip underlining the symbol for actual mass in classical physics, but then one needs to be careful to specify the context in which m is used. As used here, m in quantum theory is *never* the same as the m used in classical physics in general, and general relativity in particular.

The obvious question now becomes: What is the physical justification for defining actualizable mass? Axiom III will address this question, but let us first consider the following plausibility argument to motivate it. Consider any geometric object or volume of space and imagine it could be shrunk in size without changing its shape. A geometric property that does change proportionally with size, regardless of inherent composition, is the ratio of its surface area to volume A/V. This ratio becomes larger as the object becomes smaller, and therefore, very small objects are extremely flat in comparison to objects in our every day experience. For example, since for spherical objects the ratio is proportional to the inverse of the radius, a hypothetical ball of radius 10^{-11}m (roughly the Bohr radius) has an A/V ratio hundred billion times larger than a ball of radius 1 m. If we take the A/V ratio as a measure of relative dimensionality (i.e. a greater A/V ratio is taken to mean geometrically being 'more' two-dimensional) then one property that all objects of atomic and nuclear proportion have in common is that, compared to objects on our scale, they are vastly more two-dimensional.

Carrying this observation to its logical conclusion we can ask: Is there a scale at which this ratio becomes infinite? This is equivalent to asking whether there exists a scale at which volume vanishes but area does not. Axiom III postulates that the answer is affirmative. More specifically, is posits that there exists a limit in which spacetime reduces to something analogous to it but consisting of one time and two length dimensions. A natural name for this is *areatime.* Mathematically, this assumption will be expressed as follows:

Axiom III: $$\lim_{V \to 0} U_4 = |U_{3max}| \tag{6}$$

Where U_4 refers to a region of spacetime (the subscript denotes the number of constituent dimensions) in which the limit is taken as space vanishes, and $|U_{3max}|$ is defined as the maximum quantity of areatime below which a volume is precisely zero. The term 'areatime' is meant to connote that U_3 has the same metric structure as spacetime, except that it has two instead of three constituent length dimensions. Note that $|U_{3max}|$ is not an upper limit on areatime, but only a lower limit on spacetime. In other words, axiom III does not preclude the existence of quantities of areatime greater than $|U_{3max}|$, but these do not constitute a limit on spacetime. The absolute value signs on $|U_{3max}|$ are meant to indicate that Axiom III treats it as a scalar quantity without putting any constraint on its *shape.* Put differently, it is *not* assumed that in the above limit spacetime reduces to a rigid lattice, as would be the case if a volume element anywhere in space reduced to a quantity of areatime of the same shape. We will see later how this explains that, according to this theory, we would not expect to find quantized length scales. On the other hand, since (6) does not refer to any particular volume element, it follows that for every volume element spacetime must have the same quantity of areatime as its limit. That is, axiom I requires that $|U_{3max}|$ be a *constant.* This is consistent with our fundamental assumption of homogeneity of space. To summarize, (6) says that there exists a limit in which volume vanishes, and in this limit spacetime reduces to a constant quantity of areatime of variable shape.

There are several immediate consequences that arise out of this axiom:

- It sets $|U_{3max}|$ as the limit in which spacetime becomes discontinuous, or quantized. To see this, recall that a function $f(x)$ is continuous at a *iff* $\lim_{x \to a} f(x) = f(a)$. Letting $x = V$, $a = 0$ and $f(x) = U_4(V)$ we see from (6) that $|U_{3max}| \neq U_4(0)$ because the number of constituent dimensions do not match. This contrasts with the usual assumption that spacetime is continuous, which can be expressed as $\lim_{V \to 0} U_4 = 0$, reflecting a zero amount of a four-dimensional quantity.

- It provides a physical justification for defining actualizable mass. If there are entities that actually exist in areatime in this limit, then they have an intrinsic actual history in areatime, but not in spacetime. Note that the reason here for the lack of an intrinsic actual history is different from that for photons. Photons lack it because their proper time is zero; actualizable mass, on the other hand, lacks it because it *has no* such property as proper time in spacetime. It would be meaningless to ask what its proper time is, as it would be meaningless in our analogy to ask what the position of the point (x, y) in 3-space is. Given that it must however appear like actual mass it must retrospectively be associable with motion in space less than c.

- It allows us to establish a connection between size and mode of existence, because the limit serves as the boundary for a change in the mode of existence. In particular, this limit must be small relative to the scale of our everyday experience, otherwise observable phenomena arising of from the 'superposition' of actualizable objects would be a common part of our direct sense experience.

The last point permits the formulation of a final version of axiom II:

Axiom II (Final Version):
If the areatime region associated with entities that actually exist in areatime is larger than $|U_{3max}|$ then the actualizable mass associated with such entities is transformed to actual mass. (7)

From this axiom it follows that equation (5) must reflect a fundamental process in which a local region of spacetime emerges out of a local region of areatime:

$$m \xrightarrow{U_3 \to U_4} \underline{m} \tag{8}$$

Let us briefly recap what we have so far: According to this theory, there exists a lower bound on spacetime below which space disappears, but area does not. Any objects existing in this limit lack an intrinsic actual history in spacetime because they actually exist, and therefore have an intrinsic actual history, in areatime. If the spacetime manifestation of these entities can be retrospectively associated with motion $v < c$ in space, then they have a property which we call actualizable mass. The objects characterized by actualizable mass exist in a superposition of actualizable histories.
The question to be addressed now is, how can the passage of time for an object that actually exists in areatime be compared to the passage of time in spacetime? This question is particularly pertinent geometrically because the passage of time is fundamentally related to proper time, proper time is proportional to the metric interval, and the metric intervals of spacetime and areatime are naturally distinct from one another. Before presenting the axiom that addresses this question, we need to define a symmetry that arises when certain kinds of translation pairs are superposed. Figure 3 depicts the superposition of a continuous translation at a sinusoidally changing rate from $x \to 0$ and that from $0 \to y$ at the same rate, yielding a continuous translation in the counter-clockwise angular direction:

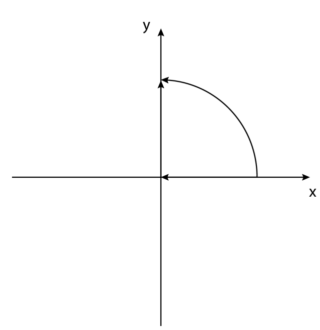

Figure 3: Superposition of one inward and one outward linear translation occurring at same rate

Figure 4 depicts all 8 such possible superpositions of translation pairs along the two axes:

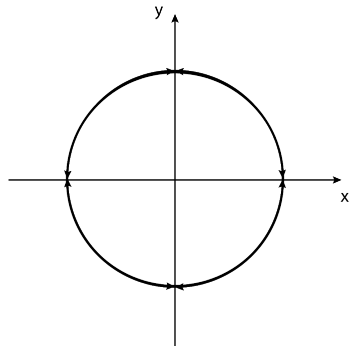

Figure 4: Angular Dual Bilateral Symmetry

Because the resultant pattern captures change in the angular direction, and is invariant both with respect to a reflection and a rotation of the axes over an angle $\frac{\pi}{2}$ (which can be thought of as a 'dual' transformation), we will call this an *angular dual bilateral symmetry.*

This symmetry can be described mathematically by a group that is analogous to the description of a vector in terms of components in some basis: just as a vector is independent of the basis, the symmetry is independent of the group description in that it is postulated to "exist in and of itself". This is what figure 4 is meant to convey. As we will see, the group description below will turn out to be very convenient in defining a formalism that applies the symmetry to the physical situation we wish to consider, but it is ultimately only one way of mathematically describing the symmetry. With this caveat, let us define the group description of the symmetry as follows: Given an angle $0 \leq \varphi < 2\pi$, an element of this group, labeled by $\mathcal{B}(\varphi)$, is given by the superposition of a clockwise and counterclockwise rotation in a 2-dimensional plane. The net rotation is therefore zero, and every element in the group is an identity transformation. The identity element is given by $\mathcal{B}(0)$ and is defined to be its own inverse. The group operation is defined as the addition of angles of same sign mod 2π. The group is abelian, associative and closed under operation. Every element $\mathcal{B}(\varphi)$ has an inverse, which, except for the identity element, is given by $\mathcal{B}(2\pi - \varphi)$. The group is therefore compact. All of the elements of this group map onto the element of the trivial group of order one.

What is the point of defining this group? We will see that it allows us to exploit the key feature of the symmetry which makes it crucial to the theory, namely that it allows for a *comparison without net transformation.* We are now ready for axiom IV.

> **Axiom IV:** *The proper time dimension of an actualizable system in U_3 is orthogonal to the proper time dimension of a system in U_4, but can be compared to it by matching the first to consecutive intervals of equal magnitude of the second according to the angular dual bilateral symmetry* (9)

Axiom IV is a concise statement of a process which requires further elaboration. The proper time of a spacetime system (e.g. a spacetime observer) will be denoted by τ (as usual), and that of a system in areatime by τ_A. Because the axiom specifically refers to an actualizable system in U_3, the interval of τ_A is taken to be related to $|U_{3max}|$ in which the system actually exists by

$$|U_{3max}| = A\tau_A \tag{10}$$

where A is the two-dimensional region associated with the system in that limit. That is because systems with $|U_{3max}| > A\tau_A$ would not even be actualizable, whereas systems with $|U_{3max}| < A\tau_A$ would have presumably already actualized by Axiom II.

This axiom postulates that τ_A is 'orthogonal' to τ [2]. Mathematically, the orthogonality is meant to be in an abstract 2-dimensional space, but it can be physically framed in terms of the concept of intrinsic actual

[2] The term 'orthogonal' is typically reserved for vectors with zero inner product. It is employed here in an unconventional sense

history, thereby connecting it with the previous axioms: *Iff*, when comparing two objects, one has an intrinsic actual history in spacetime and the other does not, then the proper times of the two are orthogonal. The point is that in order for the proper times (and the metrics to which they are proportional) to be distinct, they must be orthogonal in this sense. Note that by this definition, objects characterized by nonzero proper time (i.e. with actual mass) always actually exist in spacetime.

With this understanding of the orthogonality between distinct proper times, we can now consider how to compare them to each other, but first let us clarify why this is necessary in the first place. We wish to describe the observations by spacetime observers of effects caused by a system which actually exists in areatime. Since for spacetime observers and the areatime systems there can be no shared passage of time (else the areatime system would have an intrinsic actual history), how can one meaningfully describe any such observations occurring over finite duration? If we can in fact attribute observational consequences over a finite time interval to entities that exist in areatime, then there must be a mechanism by which the passage of time in the system that is being observed (the *time evolution* in the language of QM) is compared to the passage of time for the observer.

Axiom IV provides the mechanism: The postulated symmetry makes it possible to compare the passage of time between the two without leading to a net transformation (e.g a rotation over any nonzero angle). A net transformation would destroy the orthogonality of the proper times because it would then be possible to express one proper time in terms of the other, causing them therefore to no longer be distinct. To see how the symmetry does this, re-express τ_A as

$$\tau_A = (\tau_A)_f - (\tau_A)_i = \frac{|U_{3max}|}{A} \tag{11}$$

where $(\tau_A)_f$ and$(\tau_A)_i$ correspond to the initial and final proper temporal boundaries of $|U_{3max}|$. The next part of Axiom IV says that τ and τ_A can be compared against each other by matching τ_A to consecutive intervals of equal magnitude of τ. This is only possible if we *identify* the two opposite temporal boundaries of τ_A, which in turn introduces the property of *periodicity* to τ_A:

$$\tau_A \Rightarrow \tau_A + n\frac{|U_{3max}|}{A} \qquad n = 0, 1, 2... \tag{12}$$

The last part of axiom IV says we match τ_A to τ according to the angular dual bilateral symmetry. We take it a given as part of axiom IV that τ and τ_A scale the same under the symmetry (i.e. that unit distances have the same meaning along either interval). The convenience of the group description of the symmetry now becomes evident because it allows us to think of it as two simultaneous rotations over an angle $\varphi = 2\pi$ in opposite directions. Fig. 5 shows how this can be visualized:

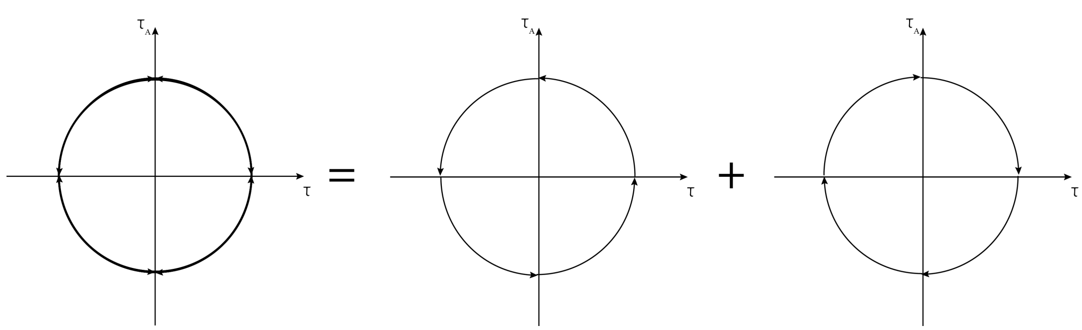

Figure 5: Decomposition of Angular Dual Bilateral Symmetry into 2 opposite rotations

The duration over which each rotation completes a cycle is proportional to τ_A, so

to emphasize that, since the (squares of the) metric intervals proportional to the proper times themselves have constituents that can be viewed as analogous to the components of a vector, the perpendicularity between them may also be viewed as analogous to the orthogonality of vectors. The purpose of this terminology is to stimulate a new perspective on the relations between metric intervals of different spacetimes, but the purist may still substitute 'perpendicular' whenever 'orthogonal' is encountered.

$$\tau_A \propto \frac{T}{2\pi} \tag{13}$$

Where the period T parameterizes the periodicity of τ_A for one of the rotations. Because τ_A and τ are presumed to scale the same, the magnitude (actually the modulus, as we will see momentarily) of the proportionality constant must be equal to one. Yet, by our group description, the rotations must occur simultaneously, so each value of τ_A actually maps to *two* values of T: One corresponding to the clockwise rotation and the other to the counterclockwise rotation. Since they can be thought of as 'time-reversed' versions of each other, they can be distinguished by including a $\pm$sign on the right side of (13), where each sign corresponds to one of the rotations:

$$\tau_A \propto \pm\frac{T}{2\pi} \tag{14}$$

The symmetry (and, indeed, the group description) only holds over the duration of a *single period* of simultaneous rotations over 2π. In subsequent periods, τ_A is matched up against subsequent intervals of τ, and this means that a rotation in both directions over the angle $\varphi = 2\pi$ does not return one to the starting point. If we think of τ_A as the range of φ , and of τ as its domain and take τ to be so much larger than τ_A that by comparison $\tau \approx \infty$ (since an observer in spacetime could, in principle, carry on an experiment 'forever'), we can consider the domain of φ to be infinite. *This mathematically defines an imaginary angle!* In other words, the angle that is defined by the relation between τ_A and τ is actually $i\varphi$ where $i \equiv \sqrt{-1}$. *This* is the proportionality constant:

$$\tau_A \ = \pm\frac{T}{i2\pi} = \mp i\frac{T}{2\pi} \tag{15}$$

consistent with the fact that the range of an imaginary angle is itself imaginary. Imaginary numbers were discovered several hundred years ago, and their appearance in equations that model the real world (to wit: Schrödinger's equation) has been one of the main mysteries associated with quantum theory. The framework here suggests a clear mathematical reason for their necessity, but one can also attach to it a physical interpretation distinct from the mathematical reason given above: τ_A does not exist as such in spacetime; if it did, then entities existing in spacetime would age along τ_A, but they actually age along τ, which is real. Thus, τ_A must be modeled as an imaginary quantity of time in spacetime.

It may have been noticed that so far, this framework has had something of a 'geometric' flavor: We have mentioned spacetime, areatime and proper time but not yet any dynamical quantities such as Energy and momentum, and Planck's constant has so far been conspicuously absent. This is evidence that this framework stands on its own without *a priori* need for an appeal to a knowledge of quantum mechanics. The next axiom, however, will directly connect this framework to known quantum theory:

$$\textbf{Axiom V}: \quad \tau_A = \mp\frac{i\hbar}{mc^2} \tag{16}$$

where m refers to the actualizable mass. It is readily admitted that this is the least 'natural' of the five axioms, in the sense that the equality between the two sides does not seem to be well-motivated by intuitive physical reasons. We speculate that a deeper reason for this equality may be found within the context of quantum field theory. Here we are however mainly concerned with recovering standard quantum mechanics, and for this purpose, the statement of axiom V is sufficient.

3 From the Dimensional Theory to Quantum Mechanics

In this section we will attempt to recover the path integral formulation of standard non-relativistic quantum mechanics from the framework that was just presented. Our strategy will be as follows: First, transform the angular dual bilateral symmetry in a form that is identical to the relativistic form of the quantum phase; re-express the phase using axiom V and take the non-relativistic limit; re-express each actualizable history in terms of a distinct actualizable path and associate the phase with each path, since the phase is the means by which the passage of time in areatime and in spacetime as the actualizable path progresses are compared; finally, Integrate over all possible paths to obtain the path integral.

To begin, we identify each of the two rotations into which the symmetry was decomposed with a phase.

The two phases are then complex conjugates of each other and, as mentioned, must be considered to be simultaneous instead of consecutive to be consistent with the group description of the symmetry. Considering for the moment only one of the two phases, for any interval $2\pi n \leq \varphi \leq 2\pi(n+1)$, $n = 0, 1, 2...$, the real angle φ is given by

$$\varphi = \tan^{-1}\left(\frac{\tau_A}{i}\frac{1}{\tau}\right) \tag{17}$$

Where τ_A is divided by i to make it real. The phase amplitude τ_r is given by

$$\tau_r = \sqrt{\tau^2 + \left(\frac{\tau_A}{i}\right)^2} \tag{18}$$

To transform this phase into the quantum phase we must normalize the amplitude and render it dimensionless. This can be accomplished by defining a new angle θ such that

$$\theta \equiv \cot\varphi = \cot\left(\tan^{-1}\left(\frac{\tau_A}{i}\frac{1}{\tau}\right)\right) = i\frac{\tau}{\tau_A} \tag{19}$$

Then we can define a new Argand plane consisting of the orthogonal axes x and iy such that over a single period the real angle θ is given by

$$\theta = \tan^{-1}\left(\frac{y}{x}\right) = i\frac{\tau}{\tau_A} \tag{20}$$

From which it follows that

$$\frac{y}{x} = \tan\left(i\frac{\tau}{\tau_A}\right) = \frac{\sin\left(i\tau/\tau_A\right)}{\cos\left(i\tau/\tau_A\right)} \tag{21}$$

The new amplitude r is then given by

$$r = \sqrt{y^2 + x^2} = \sqrt{\sin^2\left(\frac{i\tau}{\tau_A}\right) + \cos^2\left(\frac{i\tau}{\tau_A}\right)} = 1 \tag{22}$$

which is normalized and dimensionless, as required. Since τ_A is periodic, we can identify it with the inverse of an imaginary angular frequency

$$\tau_A = \mp i\frac{T}{2\pi} = \mp\frac{i}{\omega} \tag{23}$$

Where the $\mp$sign indicates that we are now again considering both phases. Then the imaginary angle $i\theta$, which is now a parameterization of $i\varphi$, is given by

$$\mp i\theta = i\left(i\frac{\tau}{\tau_A}\right) = \mp i\omega\tau \tag{24}$$

Using (24) we can describe the phases mathematically as

$$e^{\left(-\frac{\tau}{\tau_A}\right)} = e^{\mp i\omega\tau} \tag{25}$$

This is the relativistic form of the quantum phase. Letting $\tau = \int d\tau$ [3] and using axiom V together with equation (23) to let $\omega \equiv \frac{mc^2}{\hbar}$, we get

$$e^{\mp i\frac{mc^2}{\hbar}\int d\tau} = e^{\mp i\frac{mc}{\hbar}\int ds} = e^{\pm i\frac{S}{\hbar}} \tag{26}$$

Where $S = -mc\int ds$ is the classical relativistic action of a free particle. We can also rewrite this as

$$e^{\pm i\frac{S}{\hbar}} = e^{\pm\frac{i}{\hbar}\int Ldt} \tag{27}$$

[3]the integration constant can be absorbed into the normalization of the path integral at the end

where $L = -mc^2 \int \frac{dt}{\gamma}$ is defined as the relativistic Lagrangian of a free particle. Let us consider a single free particle in the non-relativistic limit so that particle number (and therefore mass) and type is conserved. The equation can then be approximated by

$$e^{\pm \frac{i}{\hbar} \int Ldt} \approx e^{\mp \frac{imc^2}{\hbar} \int (1 - \frac{v^2}{2c^2}) dt} \tag{28}$$

Notice that the first term in the exponential on the right is independent of the motion of the particle and only depends on the mass term and the time integrand. But by assumption m is constant in our approximation, so we can rewrite this as

$$e^{\mp \frac{imc^2}{\hbar} \int (1 - \frac{v^2}{2c^2}) dt} \equiv \mathcal{A}(t) e^{\pm \frac{i}{\hbar} \int \frac{mv^2}{2} dt} \tag{29}$$

where $\mathcal{A}(t) \equiv e^{\mp \frac{imc^2}{\hbar} \int dt}$, so that what remains of the exponential is the time integral over the non-relativistic Lagrangian and its negative. We now apply axiom I to this situation since, by virtue of being the manifestation of something that actually exists in areatime, the actualizable particle does not have an actual history in spacetime, and is thereby subject to that axiom. But that means that now equation (29) no longer describes a single particle but an infinite number of particle manifestations in spacetime, each associated with a distinct actualizable history, of something that exists in areatime. To put this in a mathematically more tractable form, we associate with each actualizable history an *actualizable* path and subdivide this path into very small elements. For simplicity, we will consider here a model in which the paths are along one spatial dimension. The equal-weightedness of the superposition of actualizable histories ensures an equal-weightedness in the superposition of paths. Correspondingly, we subdivide the time it would take for the actualizable particle to traverse the actualizable path and subdivide this into very small elements as well. Then, one regards each actualizable path as something one gets by starting at some initial time from the first element of the path to the next element at the next instant and so on until one has reached the final element, having started with the first one. Mathematically, this way of looking at the situation is expressed in terms of what is called the *propagator*, and when it is applied to all possible paths over two endpoints a finite distance $x - x'$ apart which are traversed over a finite time interval $t - t'$, we will symbolize it by $U(x, t; x', t')$. Note that this breaks the angular dual bilateral symmetry because we have chosen a direction in time. The discretization of the path also requires a corresponding discretization in the exponent in equation (29). To do so, we define $\epsilon \equiv \frac{t-t'}{N}$ where N is the number of time intervals into which we have divided the integral, and then re-express the integral in the exponent as

$$\int_{t_i}^{t_f} \frac{mv^2}{2} dt \to \sum_{i=0}^{N-1} \frac{m}{2} \left(\frac{x_{i+1} - x_i}{\epsilon} \right)^2 \epsilon \tag{30}$$

In the limit in which $N \to \infty$ and therefore $t \to 0$ we then obtain

$$U(x, t; x', t') = \lim_{N \to \infty, t \to 0} \mathcal{A}(\epsilon) \times ... \mathcal{A}(t_i - t_{i-1}) \times ... \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} ... \int_{-\infty}^{\infty} \exp \left\{ \frac{im}{2\hbar} \sum_{i=0}^{N-1} \left(\frac{x_{i+1} - x_i}{\epsilon} \right)^2 \epsilon \right\} \times dx_1 ... dx_{N-1} \tag{31}$$

The infinite integrals are required so that the small path elements can be added in all possible ways to give all possible paths. Let us now consider the coefficient $\mathcal{A}(t)$: it turns into the product of $N - 1$ coefficients, each of which is associated with one of the integrals. However, in the specified limit, the product reduces to

$$\lim_{N \to \infty, \epsilon \to 0} \prod^{N-1} \mathcal{A}(\epsilon) = \mathcal{A}^{\infty}(0) \equiv \mathcal{A} \tag{32}$$

The actual value for $\mathcal{A}$ will turn out to be determinable by normalizing the product of the integrals at the end. Incidentally, this may suggest an (admittedly not very intuitive) explanation for why rest mass plays no visible role in the non-relativistic limit. The usual procedure for evaluating the product of the integrals itself is well-understood and can be carried out as follows[4, 5]: First, the x_i variable is substituted with one that absorbs the constants in the exponent to make the integration easier. Then, the integral with respect to the first indexed variable is performed using the well-known Gaussian integral formula. Evaluating subsequent integrals in indicial sequence reveals that the solution can be generalized by induction to a formula for the value of the product all the integrals:

$$U(x,t;x',t') = \mathcal{A} \lim_{N\to\infty,t\to 0} N^{-1/2} \left(\frac{2i\pi\hbar\epsilon}{m}\right)^{\frac{N-1}{2}} e^{\frac{-m(x-x')^2}{2i\hbar N\epsilon}} \tag{33}$$

This usual expression for the quantum mechanical propagator for this situation can be obtained in the appropriate limit by setting

$$\mathcal{A} = \left(\frac{m}{2i\pi\hbar\epsilon}\right)^{N/2} \equiv \mathcal{C}^{-N} \tag{34}$$

and defining

$$\int \mathcal{D}[x(t)] = \lim_{N\to\infty,t\to 0} \frac{1}{\mathcal{C}} \prod^{N-1} \left[\int_{-\infty}^{\infty} \frac{dx_1}{\mathcal{C}}\right] \tag{35}$$

We can then rewrite the product of the integrals in the appropriate limit in equation (31) as

$$U(x,t;x',t') = \int_{x'}^{x} e^{\frac{i}{\hbar}S}\, \mathcal{D}[x(t)] \tag{36}$$

Where S here now refers to the nonrelativistic action. When the propagator is expressed in this form, it is called the *path integral* from x' to x. Note that (36) only represents the square root of all the actualizable manifestations in spacetime, because we broke the dual angular bilateral symmetry when we chose a preferred direction in time to construct the path integral. The full angular dual bilateral symmetry mathematically corresponds to the sum of two opposite rotations over 2π, or, equivalently, the product of the complex conjugate phases.

We have recovered a description that looks exactly like the basic Feynman path integral formulation of quantum mechanics for a single free particle in a 1-dimensional model [6], except that it distinguishes between actual and actualizable paths, histories and particles, whereas the standard formulation makes no such distinctions. The wave function satisfying Schrödinger's equation derived from applying this path integral to an initial wave function Ψ_0 is

$$\Psi = \int_{-\infty}^{\infty} \Psi_0 \int_{x'}^{x} e^{\frac{i}{\hbar}S}\, \mathcal{D}[x(t)] \tag{37}$$

and describes an actualizable state, in the sense of the distinction indicated by the left side of equation (1). The actualization of this state, governed by axiom II, presumably occurs when that part of a detector directly interacting with the particle manifestation forms a 'complex' that in areatime corresponds to something in a region that exceeds the limit $|U_{3max}|$. Note that both signs of the phase are required in standard quantum mechanics to calculate the probability for actualizing into one of the possible eigenstates because in that calculation the complex phase must be multiplied by its complex conjugate. From the perspective of this derivation, the requirement is due to the fact that only the product of the two conjugate phases leads to the full angular dual bilateral symmetry. This, in turn, ensures (1) that the net phase change is zero, which reflects a net zero transformation of progression along τ_A to progression along τ and (2) that all of the actualizable manifestations in spacetime are included in the representation of the entity that actually exists in areatime.

Given this framework, it is easy to understand conceptually why the path integral approach, modified to the field integral, is so successful in quantum field theory. In the relativistic limit, when particle number and type is no longer conserved, it seems to become practically unavoidable to consider, instead of the actualizable histories of individual particles, the actualizable histories of every point in spacetime. This in turn, seems to be the most direct indication that spacetime itself emerges out of areatime.

4 A New Look at some Old Quantum Mysteries

The Dimensional Theory suggests new insights into some of the deepest conceptual difficulties of quantum mechanics, but also raises some new questions:

- *Why the quantum?* Planck's constant is proportional to the commutator of conjugate variables, so a zero value would cause the non-commutativity to vanish, and hence cause the mathematical formalism of quantum mechanics to become reducible to that of classical mechanics. The reason for the non-zero value of $\hbar$ according to the dimensional theory can be found by comparing equation (11) with equation (16):

$$\frac{|U_{3max}|}{A} = \mp\frac{i\hbar}{mc^2} \tag{38}$$

We can interpret the variables in this equation to be A and mc^2. Defining $\frac{i\hbar}{|U_{3max}|} \equiv k$, we can rewrite this as

$$mc^2 = \mp kA \tag{39}$$

This indicates that behind the abstract concept we call *Energy* there is a more fundamental concrete quantity, namely *Area*. Through this novel conceptualization of Energy we can understand that there has to be a quantum if a finite quantity of areatime bounds spacetime from below, as postulated by axiom III. It also predicts that $|U_{3max}|$ would not be directly observable to us through the quantization of space: The direct observation of smaller distances requires higher energies, but by our new conceptualization this means that the limit $|U_{3max}|$ is 'flattened' out (since its shape, but not value, was postulated to be variable) in exactly the right way in order to prevent the observation of quantized length scales.
It seems that the interpretation of Energy in terms of Area also entails a deeper interpretation of mass in terms of a quantity of *time squared*, but it is more difficult to assign an obvious meaning to this. Ultimately, such an interpretation, properly understood, should tell us what mass *is*, which in turn should help us understand the physical origin of the mass relations between the elementary particles in the standard model. That mass is at a more fundamental level to be understood as a squared quantity is empirically suggested by the intriguing formula, first discovered by Koide, describing the relations between the experimentally determined lepton masses [7].

- *How to conceptually understand the wave-particle duality?* To answer this, let us build a visual model based on the theory. Consider first that equation $r = a$ (where a is some arbitrary number) would be represented in space as a sphere of radius a, the surface of which consists of points which are only actualizable because the equation does not specify the angles, as depicted in figure 6.

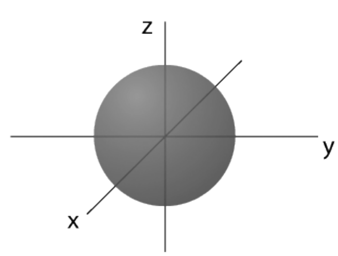

Figure 6: A sphere with a surface consisting of actualizable points

For $r = 0$ the sphere reduces to a point. The expression $r = 0$ is also used to denote zero distance in Euclidean space, which can be differentially expressed as $dr = 0$. The Minkowski spacetime version of this is, of course, $ds = 0$, which can also be written as $\sqrt{c^2dt^2 - dr^2}$, a spherical surface expanding at the speed of light, the light cone. To give this a physical interpretation in light of the theory, we must re-interpret the actualizable points that make up the surface as actualizable particles. This can be done by imagining that a detector surrounding the expanding sphere capable of detecting actual localized particles anywhere on the interior of its surface is used to mark all the positions on the sphere on which a actual particle could be detected. So far we only have an expanding *surface*, but because it consists of actualizable particles, the symmetry between the proper times must be included in their description.

Since the actualizable particles are moving at c, however, their proper time is zero. This problem can be overcome by considering an affine parameter and choosing it in such a way that it behaves exactly like proper time. Once each actualizable particle is associated with the affine parameter, the spherically expanding surface is transformed into a spherically expanding *wave*. One may then imagine how the spherical wave travels through a barrier with two slits, and that right after its passage through the barrier, the two slits act as sources of new spherical waves which interfere with each other. When the wave fronts reach a screen behind the barrier the actualization process causes the actualizable wave to collapse to the point-like locus of actualization. Strictly speaking, an actualizable particle traveling at c does not actualize, it simply vanishes. The model is basically the same for massive particles, except that rather than being confined to the surface of the light cone, the spacetime manifestation of the entity that actually exists in areatime extends everywhere within. This model describes a wave-particle duality that appears to be exactly the same as that described by standard quantum mechanics.

- *How to conceptually understand entanglement?* One of the most profound mysteries of quantum mechanics is the fact that measurements on one of a set of particles described by the same non-separable wavefunction can influence the outcome of measurements on the others 'instantaneously', as it were. How this can be understood in terms of the theory is discussed in some detail in reference [8]. A brief explanation is as follows: Since being describable by a wavefunction implies actual existence in areatime, and metric intervals in areatime are distinct from those in spacetime, there is between the actualizable entities described by that wave-function a metric relation which is independent from the spacetime metric. Hence, it is possible to consider the influence to reflect events which are local in areatime but appear non-local in spacetime. That in order to observe the influence the particles must be actualized enforces the fact that the influence can only ever be observed as (classically) unexpected correlations between measurement outcomes.
  In a relativistic context there is the added mystery that for spacelike separated measurements, the direction of the influence seems to be observer-dependent because the time ordering of measurements can vary by observer. That actualizable particles have no proper time in spacetime implies that they do not have worldlines, and this in turn means that, for spacelike separated measurements, there exists no privileged reference frame according to which the direction of the influence can be determined because until the subsequent measurement (in whatever frame) is performed, there is 'nothing there' in spacetime to influence.

Alas, one quantum mystery to which this framework, at least as developed so far, does not seem to be able to provide a definite answer is whether quantum mechanics is stochastic or deterministic. So far, it appears that either possibility is consistent with what has been described: It seems possible that in the emergence process, all information about the configuration in areatime giving rise to a particle in spacetime is coarse-grained so as to specify what type of particle it is, but that other information, such as its position and momentum is determined stochastically. On the other hand, it seems also possible that the configuration in areatime associated both with the actualizable particle and that part of the detector with which it interacts to yield the actual particle may fully determine these other properties. In that case, the theory would be a non-local contextual hidden-variable theory, with the 'hidden variables' being the configuration of events in areatime. Interestingly, the second possibility would seem to realize something remarkably similar to the holographic principle, in the sense that the information in a region of space is encoded in a lower-dimensional spacetime. Because the standard holographic principle takes the region in which information is encoded to be the boundary of spacetime and the region of areatime from which spacetime emerges is not a boundary of the latter in the usual sense, this possibility cannot be identified with the holographic principle proper. To make the distinction clear, one might call the principle implied by the deterministic possibility *holographic emergence*.

Perhaps it may be possible in the future to devise an experiment that can distinguish between these two possibilities within this framework.

5 The Relation Between Quantum Theory and Relativity

One theoretical factor which may inspire greater confidence in a new theory is whether it can connect phenonema that are ostensibly completely unrelated to one another. It turns out that it is possible to connect the framework just presented to the invariance of the speed of light, which is in the standard formulation of special relativity (SR) a postulate that lies at its foundation. Some time ago, this author presented a derivation of this postulate based on three axioms [9]:

$$\textbf{SR Axiom I:} \qquad v_\tau \equiv \sqrt{c^2 - v^2} = \frac{c}{\gamma} \tag{40}$$

Where $v_\tau = c\frac{d\tau}{dt} = \frac{ds}{dt}$ is defined as *motion in proper time* and can be thought of as a an 'aging' parameter with dimensional units of speed. Although this postulate yields much of the mathematical structure of SR, it is by itself insufficient to derive the speed of light invariance because it is also compatible with a universe in which v_τ is invariant and therefore c is not. The realization that for $v = c$, $v_\tau = 0$ implies a zero duration of existence in spacetime and yet is associated with entities that are empirically known to exist was called the existence paradox, and was addressed using a quasi-philosophical principle called the principle of least speciality, according to which we should not regard aspects of nature as 'special' unless compelled by logical reasons to do so. Applied to spacetime itself, this principle leads to the assumption that spacetime is not 'special', in the sense that it is not a unique repository for the existence of objects, since there is no known logical reason why it must be so. This, in turn, permits the assumption that objects with a zero duration of existence in spacetime exist outside of it, which is formally expressed as a second axiom:

SR Axiom II: *If all possible observational consequences are consistent with a zero rate of aging of an entity in the frame of an observer($v_\tau = 0$), then that entity actually exists in a continuum other than that of the observer, otherwise it actually exists in the same continuum as that of the observer.* (41)

Here, the word 'continuum' is to be understood as a general term for spacetime, and is not necessarily meant to imply that it is continuous. Also, this axiom and the next as stated here are slightly modified from the original version by including the qualifier 'actual' when referring to the existence of an entity. With this, we only need one last axiom to assert the transitivity of actual existence:

SR Axiom III: *If an entity A actually exists in the same continuum as an entity B, and B actually exists in the same continuum as an entity C, then A actually exists in the same continuum as C.* (42)

Speed of light invariance follows straightforwardly from these three axioms: Consider two spacetime observers in frames O and O' in the standard configuration, which are in relative motion and suppose that O' 'emits' an object which is associated with $v' = c$ in his frame. Then by SR axiom I, $v'_\tau = 0$ and by SR axiom II, the object actually exists in a spacetime other than that of O'. But by SR axiom III, this means that it must also actually exist in a spacetime other than that of O, since, by assumption, O and O' actually exist in the same spacetime. This implies, by SR axiom II that it must be associated with $v_\tau = 0$ in the frame of O, or, by SR axiom I, $v = c$. Both observers therefore associate the same speed c with this object. Notice that SR axiom I is a theorem in the standard formulation of SR, and SR axiom III should seem very intuitive. Only SR axiom II seems highly unorthodox under the current paradigm, but if the 'other continuum' is identified as areatime, then the invariance of the speed of light becomes tightly connected to the foundations of quantum theory.

While this framework connects the foundations of quantum theory and special relativity, it actually segregates the domains of validity between quantum theory and general relativity. To see this, consider the equivalence principle (EP), which lies at the heart of general relativity, expressed explicitly in terms of actual inertial and gravitational masses [10]:

$$\underline{m}_i = \underline{m}_g \tag{43}$$

and consider that in light of equation (5) it makes no reference to actualizable mass. The fact that equation (43) exclusively refers to masses which are not in a superposition confirms that it must refer to actual, and never to actualizable masses. But that implies that *actualizable mass lies outside the domain of validity of General Relativity*. Since it is actualizable mass, however, which plays a central role in quantum theory, the domains of quantum theory and general relativity are sharply segregated: If a system exists in an actualizable state, m_i is an actualizable inertial mass, and hence subject to a description by quantum theory but not subject to the EP and therefore GR (since the EP only applies to 'classical' or actual i.e. non-superposed masses), and if a system collapses to an actual state, $\underline{m}_i$ is an actual inertial mass, and hence no longer

subject to quantum theory (since the system to which it belongs does not obey Schrödinger's equation, at least for a very brief period of time), but now it is subject to the EP and therefore GR. What this means is that *the actualization of a system must correspond to the creation of a gravitational field*, since it is only through the actualization of mass that the gravitational mass enters into the description of a system.
The claim made here is rather extraordinary and must therefore be supported by extraordinary evidence. One such evidence would be the confirmation of a predicted experimental outcome that would be utterly unexpected under the current paradigm. We shall now issue one such a prediction. In 1931, Tolman, Ehrenfest and Podolsky found that according to GR in the vicinity of a 'thin pencil of radiation' of length l in the x-direction and associated with energy density ρ a test particle placed at a point $x = l/2$ halfway between the two ends in the $z = 0$ plane should experience an acceleration towards the pencil given by

$$\frac{d^2y}{dt^2} = -\frac{2\rho l}{y\sqrt{(l/2)^2 + y^2}} \tag{44}$$

which is the special case of a more general expression they derived for the acceleration experienced by a test particle in the vicinity of a narrow beam of electromagnetic radiation in vacuum [11].
On the other hand, since photons never actualize, the framework presented here predicts that there is no such thing as actual inertial or gravitational mass associated with radiation, and hence it predicts that under the same circumstances

$$\frac{d^2y}{dt^2} = 0 \tag{45}$$

We emphasize that the claim here is not that general relativity is wrong, but rather that, if the ideas presented here are correct, equation (44) represents an instance in which a theory is unwittingly extrapolated beyond its domain of validity. Nonetheless, the new prediction is highly unexpected because general relativity has so far withstood every experimental and observational challenge to which it was subjected, including those provided by the effect of gravitational fields on radiation (e.g. the bending of light) [12]. Given that we know empirically that such effects occur, the prediction given in (45) might be regarded as, in effect, the prediction of a violation of conservation of momentum. However, from the perspective of the dimensional theory, the gravitational field does not interact with photons. Rather, it curves the background spacetime, resulting in a path integral of actualizable paths over a spacetime region that due to its geometry skews the overall result such that the 'classical' path of light appears bent to us. The photons themselves, however, as objects which intrinsically exist areatime, experience no momentum exchange with the gravitational field. On this view, the fact that we have already observed such phenomena as, say, gravitational lensing is no argument to discount the prediction given in (45). Of course, once the radiation is absorbed, the gravitational mass of the absorber increases by an amount proportional to its energy ('absorption' counts as an actualization event for the absorber), hence resulting in a stronger gravitational field while the absorber exists in an actual state.
The experiment proposed here offers a definite but indirect way of falsifying the dimensional theory. A more direct experiment would measure the gravitational field of an actualizable massive quantum system, but the challenge then is to ascertain that, as the measurement takes place, the system does not actualize i.e. collapse to an actual state. If this can be done, the predicted result would, once again, be null. Note that, as with radiation, the converse need not be true: Indeed, it has already been already observed that neutrons traveling in a gravitational potential "fall" in accordance with the equivalence principle [13], but once again, that is here not ascribed to an intrinsic interaction with the quantum object as it exists in areatime but just to the fact that the background spacetime geometry skews every path integral in the same way.
Put very simply, gravity is according to the dimensional theory an epiphenomenon and has no existence at the level of areatime; to test this idea, we need to measure the gravitational fields of the actualizable spacetime manifestations of entities which intrinsically i.e. actually exist in areatime.

6 Further Vistas: A Metatheory of Nature?

In this section, we will indulge in some untamed speculations about generalizing the ideas behind the dimensional theory in order to stimulate thinking about open problems in fundamental physics along entirely new lines.

The straightforward extension of this framework that is suggested by the principle of least speciality presumes that the emergence of spacetime from areatime can be generalized using the plausibility argument for axiom III, namely that *size implies dimensionality*:

$$U_2 \to U_3 \to U_4 \to U_5 \ldots \tag{46}$$

Indeed, very recently several researchers have proposed an extremely similar idea, except that it appears to be based on a rigid-lattice model with fundamental length scales which, as we saw, is incompatible with this theory [14, 15].

If it was really the case that events at the level of U_2, what one might call *lengthtime*, were to manifest themselves to us, we would expect to associate the manifestations (1) with comparatively small distance scales because the lowest dimensionality reflects the smallest size, and (2) with more complicated symmetries than the $U(1)$ symmetry group, because the manifestation would have to rise through an additional 'layer' of dimensionality before becoming observationally accessible to us. Intriguingly, both of these qualitative conditions are met by the strong and weak force, suggesting that there may yet exist a more fundamental way of thinking about them.

At the other end of the size spectrum, if events at the level of U_5, which one might call *4-spacetime*, were to manifest themselves, we should expect to observe phenomena at very large scales that are altogether undetectable at the scale of our own existence because to us these would be manifestations of higher-dimensional epiphenomena in a universe that, at their scale, really consists of four (or more) spatial dimensions. Again, it is intriguing that this qualitative suggestion seems to agree with the currently unexplained phenomena we call Dark matter and Dark Energy and again, several researchers have proposed similar ideas [16, 17]. At least with respect to Dark matter, the suggestion is potentially empirically falsifiable: The detection of a 'dark matter particle' at the Large Hadron Collider or by means of any other experiment would immediately rule it out.

If these speculations are borne out by more substantial quantitative theories, then the 5 axioms presented here represent only part of a *metatheory* i.e. a theory which expresses the relation between various theories that describe the observational manifestations of events and observers in various combinations of spacetimes. The classification of these theories relative to the observer would then require the definition of a more primitive concept of a reference frame that is not a function of the position of the observer relative to what is being observed, but of the dimensionality of his frame. One can call this concept a *Dimensional Frame of Reference* (DFR), to distinguish it from our usual notion of a reference frame (which, if the distinction needs to be made explicit, could be called a *positional frame of reference* (PFR)). If, say, the strong force really was found to be ultimately due to events in U_2, then QCD could be categorized as the theory that describes events in lengthtime as observed by observers with a 3-DFR (the number refers, of course, to the spatial dimensions associated with the dimensional frame). Assuming that the general ideas which led to the association of quantum phenomena with areatime events carry over to higher dimensions, then there would even be a place for a quantum theory of gravity: It would be a theory of spacetime events as they manifest themselves to observers with a 4-DFR, with the theoretical description of the same events given by observers with a 3-DFR being General Relativity. To be sure, some theories, like classical electrodynamics, may not fit this classification neatly unless they are thought of as approximations to more fundamental theories which do.

Such a taxonomy of theories seems to blur the distinction between physics, metaphysics and mathematics, for it allows one to construct mathematical theories which are in principle untestable by us (like a theory of quantum gravity in the aforementioned sense), yet be testable theories of nature for another kind of observer (in this case, one who hypothetically exists in U_5). A metaphysical question like why our universe seems to be 4-dimensional, perhaps considered up until now unanswerable by science, would suddenly have a trivial answer, namely because we happen to be the right size to observe it as such. Indeed, the question of the 'size' of the universe would now have to be addressed in a more nuanced way to take dimensionality into account. In short, the speculative extensions of the framework presented here suggest that nature may be much richer than we had imagined.

7 Conclusion

This paper presented the dimensional theory. It attempted to show that from this theory one can derive the path integral formulation of quantum mechanics; that it renders some of the deepest mysteries of standard quantum mechanics amenable to simple conceptual understanding; that it may connect the foundations of quantum theory to the foundations of special relativity while segregating the domains of quantum theory and general relativity, and that it leads to at least one definite falsifiable prediction, namely that the gravitational field of radiation should be zero, in contradiction to the standard GR prediction. The paper concluded with some speculations about how the theory may be extended to a metatheory of nature.

There are still several questions which this framework raises but does not answer in an obvious way. Among these are: Is a detailed description of events in areatime accessible to us? What is the precise mechanism for the wave-function collapse and the emergence of the extra dimension? What is the fundamental meaning of mass in terms of a quantity of time squared? Would such an understanding allow us to predict the relationships between the elementary particle masses, and permit an understanding of related problems, such as the origin of the Koide formula and the family problem? Is it really possible to re-express the strong interactions in terms of interactions in lengthtime?

It seems likely that if this framework offers answers to these questions, then they are to be found in a field theoretic generalization. As such, it may offer a new way of approaching an understanding of a familiar subject.

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