Quantum Superposition, Mass and General Relativity

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Abstract

The quantum superposition principle, which expresses the idea that a system can exist simultaneously in two or more mutually exclusive states is at the heart of the mystery of quantum mechanics. This paper presents an axiom, called the principle of actualizable histories, which naturally leads to the quantum superposition principle. However, in order to be applicable to massive systems, it requires introducing a novel distinction between actualizable and actual mass. By means of arriving in conjunction with two previously introduced axioms at the path integral formulation of quantum mechanics, it is shown that actualizable mass is the central concept of mass in quantum theory, whereas actual mass is the central concept in classical theories, and in particular general relativity. This distinction sharply segregates the domains of validity of the two theories, making it incompatible with any theory of quantum gravity which does not respect this segregation. Finally, an experiment is suggested to test this idea.

Keywords: Quantum Superposition, Interpretation of Quantum Mechanics, Principle of Actualizable Histories, Actualizable mass, Actualizable Path, Quantum Gravity, Dimensional Theory

1 Introduction

One aspect that uniquely distinguishes quantum theory from any classical theories in physics is the so-called quantum superposition principle. In the canonical formulation of quantum mechanics, this refers to the fact that any given quantum state can be decomposed into a linear 'sum' i.e. a *superposition* of eigenstates that are in a physical sense mutually incompatible, which in turn allows them to be mathematically modeled as orthogonal basis vectors in Hilbert Space. Although the double slit, Stern-Gerlach and similar experiments provide strong empirical support that this is indeed a correct description of quantum systems, it seems very difficult, if not impossible, to imagine what such systems would be like if they could be directly observed in such a superposition. Indeed, it is striking that in our personal experience we *never* directly observe any system in this way. Attempts to address this problem have supplied much of the speculation surrounding the interpretation of quantum mechanics. Such efforts range from collapse theories in which the system collapses from a superposition to one of the eigenstates in the observation basis, to the so-called many-worlds and related interpretations, in which the observer becomes part of the system and is thus only able to directly observe one of the eigenstates, even though the system continues to exist in a superposition [1].

This paper will present an axiom, as part of a broader framework, which leads very naturally to the quantum superposition principle. However, this axiom also implies that there is a heretofore unrecognized distinction between mass as a concept used in quantum theory and as it is used in all classical theories. This distinction is then used to show that General Relativity and the quantum theories have sharply segregated domains of validity, thus making this explanation incompatible with any theory of quantum gravity which does not respect this segregation. Finally, an experiment is suggested to test this idea.

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2 Actual vs. Actualizable Histories

Let us consider, as a sort of intuition-building exercise or warm-up analogy before presenting the real idea, a point (x, y) in a 2-dimensional Euclidean plane as represented in fig. 1.

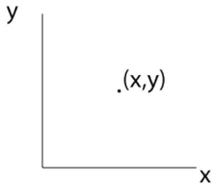

Figure 1: An arbitrary point in an xy-plane

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

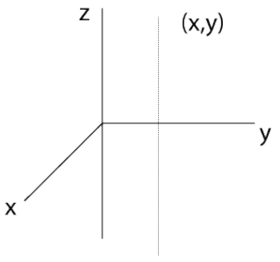

Figure 2: The same point in an xyz-space with the same xy coordinates as before now manifests itself as a superposition of an infinite number of *actualizable* points, one for each possible z-coordinate

This change in the characterization 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 a *linear superposition* of 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. The superposition is "linear" because each point contributes to it equally. Note that for any *actual* point in 3-space i.e. a point specified by three coordinates, it is impossible to be characterized by two distinct z-values; distinct z values are *mutually incompatible* as properties of one and the same actual point in 3-space. To help formalize 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, let us call the latter *actualizable* points in 3-space, where in this context this simply means 'capable of becoming actual'. What is required to transform (x, y) 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 that it is represented in 3-space:

$$(x, y) \xrightarrow{\text{`}Actualization\text{'}} (x, y, z) \tag{1}$$

Note that 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 evident that this process is remarkably similar to what is in standard quantum mechanics called the ‘wave function collapse’. Indeed, in a recent paper, this author proposed that this collapse could be understood as a process in which some physical mechanism (not necessarily observer-dependent) brings about an ontological transformation of the state of a quantum system, a process which was depicted as follows [2]:

$$|\Psi > \xrightarrow{'Measurement'} |\underline{\psi}_i > \tag{2}$$

Here, $|\Psi >$ describes the state of the system just before a measurement, and $|\underline{\psi}_i >$ describes an eigenstate in the observation basis just thereafter (both are assumed to be normalized). Underlining the post-measurement state indicates that it is an actual state whereas a typical quantum state, which is not underlined, is presumed to be actualizable. This transformation process is typically denoted by the anthropocentric word ’measurement’, but in light of what we have found a more fitting term might be ‘actualization’. This holds even though the 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 analogy just presented in conjunction with this conceptualization of the wave function collapse suggest 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 a ‘measurement’ transforms them into an actual system. The axiom to be presented now specifies what is missing. We will call this the *Principle of Actualizable Histories*:

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

Here, what we mean by an ‘intrinsic actual history’ is just what one might intuitively expect, namely a history experienced in the frame of an observer due to the passage of time. 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 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 epitomy 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. In order to avoid a contradiction when applying the principle of actualizable histories to quantum systems with which there is an associated mass, we must therefore define an *actualizable mass* which is not associated with an intrinsic actual history, and interpret equation (2) for such systems as being a consequence of a more fundamental actualization process involving the mass of its constituents:

$$m \xrightarrow{'Actualization'} \underline{m} \tag{4}$$

Here we have replaced the term ‘Measurement’ with the term ‘Actualization’, but are referring to the same underlying process. Also, we consider here for the sake of simplicity a single-particle system, but the idea can be easily generalized to multi-particle systems. 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 always exist in a superposition of actualizable histories. We shall refer to these as *actualizable objects.* We will see shortly that actualizable mass can very well 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.
The way the distinction in equation (4) is represented is chosen in order to minimize the change in notation required by the introduction of these novel concepts, 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. This obviously has implications for the relation between quantum theory and general relativity, which will be explored in section 4, but for now let us consider how it provides a physical explanation for the quantum mechanical path integral.

3 The Physical Origin of the Quantum Mechanical Path Integral

So far we see that if we interpret a system as being composed of components with actualizable mass (or no mass), then we can assign by our axiom to its components a superposition of all possible actualizable histories. But this means that they do not have an actual spacetime history, and it is fair to ask why that should be. The answer, at least as it applies to standard quantum mechanics, was presented elsewhere in recent work by this author, and the reader who is unfamiliar with it is strongly encouraged to consult it [3]. It presumes that such systems are spacetime manifestations of entities which actually exist and therefore can be said to have actual histories in *areatime*. Briefly, two fundamental axioms were introduced in that work: It was assumed first that there exists a limit, called $|U_{3max}|$, in which spacetime reduces to constant quantity of areatime of variable shape, and second that the proper time of a system which actually exists in areatime can be related to the proper time of a spacetime observer by means of what was called an *angular dual bilateral symmetry*. It was then shown that the symmetry can be decomposed into two phases of opposite sign, which by a suitable transformation can be expressed as $e^{\pm i\omega\tau}$. The phases allow for a comparison of the passage of two proper times which are independent of each other (since they are proportional to metrics which are independent of one another, the metric of areatime and that of spacetime, respectively) and can therefore thought to be in a generalized sense as being ‘orthogonal’. Considering a single particle, if we let $\omega \equiv \frac{mc^2}{\hbar}$ (where m is, of course, its actualizable, *not* actual, mass), and $\tau = \int d\tau$, we get

$$e^{\mp i\frac{mc^2}{\hbar}\int d\tau} = e^{\mp i\frac{mc}{\hbar}\int ds} = e^{\pm i\frac{S}{\hbar}} \tag{5}$$

Where $S = -mc\int ds$ is the classical relativistic action of a free particle. From here on, things should look quite familiar: Let us consider the non-relativistic limit so that the particle number is stable. To each actualizable history of the particle from a spacetime point a where it was last actualized to a spacetime point b where it actualizes again, we associate an actualizable path. This path is actualizable in the sense that it describes the progression over time of an actualizable particle (i.e. a particle with actualizable mass) along that path, which is the spacetime manifestation of something that inherently exists in areatime, much as each of the actualizable points in fig. 2 is a 3-space manifestation of the point (x, y) in our analogy. Since the entity in areatime and the observer in spacetime age along proper times which are orthogonal to one another, we must associate each path with each of the phases. That is because, as mentioned, the phases allow for a comparison of the passage of time between the spacetime observer and the actualizable particle for which no time passes in spacetime (else it would have an intrinsic actual spacetime history), even though they do not age relative to one another. Just as all of the actualizable points along the z-axis in fig 2 are required to completely represent the point (x, y) in 3-space, all possible actualizable paths between a and b are required to completely represent the underlying entity which actually exists in areatime. The superposition of all possible paths, each multiplied by each sign of the phase, then, provides a full account of the spacetime manifestation of an object which actually exists in areatime before it actualizes. The mathematics of this is well understood, and after all relevant manipulations are done, one ends up with an infinite integral of the form:

$$K(b, a) = \int_a^b e^{\frac{i}{\hbar}S(b,a)}\,\mathcal{D}x(t) \tag{6}$$

Where $K(b, a)$ is called the path integral from a to b. Note that (6) only represents the square root of all the actualizable manifestations in spacetime, because the complete representation must be associated with the full angular dual bilateral symmetry, which 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 particle [4], 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 this path integral describes an actualizable state, in the sense of the distinction indicated by the left side of equation (2). To denote the difference with standard quantum theory, we will refer to the framework introduced here, which includes the three axioms and the definition of actualizable mass, as the *Dimensional Theory*[1].

4 The Relation Between Quantum Theory and General Relativity

Although the ideas presented here may be unfamiliar, they are actually quite simple, and realizing that it is a distinction between actual and actualizable mass that is behind the superposition of (massive) quantum systems allows us to immediately draw a conclusion about how quantum theory is related to Einstein's theory of gravity, the general theory of relativity.

The current paradigm presumes that there exists a more fundamental theory, commonly called quantum gravity, in which gravity is unified with the quantum theories (QT). In what way this unification is brought about is yet to be specified, but it seems safe to assume that such unification entails a sharing of the domains of validity of aspects of GR and QT. After all, it would be hard to see how else it could be called a 'unification'. It is not difficult to show that any theory of quantum gravity, understood in this way, is incompatible with what was just presented. 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 [5]:

$$\underline{m}_i = \underline{m}_g \tag{7}$$

and consider that in light of equation (4) it makes no reference to actualizable mass. The fact that equation (7) 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

$$\frac{d^2y}{dt^2} = -\frac{2\rho l}{y\sqrt{(l/2)^2 + y^2}} \tag{8}$$

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 [6].

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

$$\frac{d^2y}{dt^2} = 0 \tag{9}$$

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[1] Strictly speaking, the theory requires considering (1) the actualization process e.g. $m \xrightarrow{'Actualization'} \underline{m}$, and (2) setting $\omega \equiv \frac{mc^2}{\hbar}$ as two additional axioms. These will be the subject of a future paper.

We emphasize that the claim here is not that general relativity is wrong, but rather that, if the ideas presented here are correct, equation (8) 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) [7]. Given that we know empirically that such effects occur, the prediction given in (9) 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 (9). 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: i.e. it is possible, and may have been already observed, that massive quantum systems traveling in a gravitational potential "fall", 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 its path integral.

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.

Interestingly, while this framework rules out the unification of general relativity with quantum theory, it ties the foundations of quantum theory directly to the foundations of special relativity, as the invariance of the speed of light has been derived from the very idea that photons (or any other objects associated with motion at c) do not actually exist in spacetime [8].

5 Conclusion

This paper presented an axiom as part of a framework called the Dimensional Theory which naturally leads to the quantum superposition principle, albeit at the cost of introducing a novel distinction between actualizable and actual mass. The former is taken to play a central role in quantum theory and absolutely no role in GR, whereas the latter is taken to play a central role in GR and only a peripheral role (when an actualization event occurs) in quantum theory. This distinction therefore segregates the domains of validity of the two theories and leads to the experimental prediction that actualizable systems, including those composed of electromagnetic radiation, have no gravitational fields.

At least to this author's knowledge, the gravitational field of an unactualized quantum system has never been measured, as such an experiment is exceedingly difficult to perform. We would like to suggest that this may potentially be one of the most significant experiments that could ever be performed to further our understanding of foundational physics, for if it really gives a null-result, it would be at least as significant in forcing a re-evaluation of our current ideas on the fundamental aspects of nature as the null-result obtained by Michelson-Morley was, except that nobody predicted their null result ahead of time[2].

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[2] and if anyone had, his or her prediction would probably not have been taken seriously until the experiment was performed

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