Interpreting Quantum Mechanics in Terms of Facts About the Universe

Andrew Knight, J.D.
aknight@alum.mit.edu

Abstract

A potentially new interpretation of quantum mechanics posits the state of the universe as a consistent set of facts, such that the relationships between objects in the universe are the information storing and instantiating those facts. A fact (or event) occurs exactly when the number or density of future possibilities decreases, and a quantum superposition exists if and only if the facts of the universe are consistent with the superposition. An example is analyzed in which the number of possibilities of N distinguishable classical objects in a discretized phase space is reduced by the introduction of chronological facts consisting of repelling impacts. It is shown how some facts have the effect of rendering impossible certain measurement outcomes of an object, independently of measurement outcomes of other objects, while some facts have the effect of correlating measurement outcomes of one object to those of another. The potential for further analysis through numerical simulation is discussed, particularly whether quantum uncertainty emerges from the specification of sufficient facts. Implications of and objections to the interpretation are briefly discussed, including the extent to which identity of objects must be preserved, the extent to which entanglement among objects must be universal, and whether this interpretation conflicts with special relativity. This interpretation may show that quantum mechanics, Planck's constant, and the discretization of spacetime are emergent phenomena that successfully and very accurately approximate a more fundamental ontology.

Keywords: interpretation of quantum mechanics; universal entanglement; unique history of facts; emergent quantum mechanics; discretization of spacetime

A Potentially New Interpretation of Quantum Mechanics

I am attempting to characterize, interpret, and explain quantum mechanics using the following set of propositions, and then more deeply explain this interpretation using a specific example.

The state of the universe is a particular chronological[1] set of facts (or events), and the relationships between objects in the universe comprise the information storing and instantiating those facts. Those facts must be consistent throughout the entire universe.

A fact occurs exactly when the number (or density) of future possibilities decreases.[2] Every fact limits future facts and is limited by prior facts. A fact does not necessarily require an "impact" or "interaction" as colloquially understood.[3]

A (quantum) superposition exists if and only if the facts of the universe are consistent with the superposition. For example, in the case of the classic two-slit interference experiment with the particle passing the double slit at time T_0, the particle is in a superposition of passing through both slits if and only if there is no fact about the particle's location in one slit or another at time T_0. If even a single photon, for example, correlated to the location of the particle in one slit or the other at time T_0, scurries away at light speed, there is a fact about the location of the particle and it cannot be in a superposition at time T_0.[4] In the unlikely event that the experiment is set up so that the photon later gets uncorrelated such that no "which-path" information is ever available, then the particle, amazingly, cannot be in a superposition at time T_0. Such a "delayed-choice quantum eraser experiment" (See, e.g., Aspect *et al*., 1982) demonstrates that whether an event occurs seems to depend on the *future* permanence of a correlating fact. In reality, the "window of opportunity" to prevent the decoherence of a superposition is extremely short, so we don't generally need to wait long before we can officially declare the happening of an event.

Quantum uncertainty (e.g., in the form of the Heisenberg Uncertainty Principle) is simply one type of superposition, in which a spread of possible positions and a spread of possible momenta are related. For instance, if a particle is tightly localized at time T_0, then the facts of the universe at that time are consistent with a wide spread of possible momenta – i.e., a superposition of many momenta exists at T_0.

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[1] Relative to some object; special relativity implications will be broached later.

[2] Really I mean "new fact." If event A necessarily implies event B, I don't mean to suggest that event B does not occur, but rather that the state of the universe is not further specified or limited by event B, so for the sake of efficiency I'll only consider events that reduce future possibilities.

[3] Elitzur *et al.* (1993) unintentionally provide a great example as to how quantum mechanical events can occur without an "interaction." Whether or not the suggested method disturbs a measured system's internal quantum state, it undoubtedly produces facts that reduce the number of future possibilities.

[4] "The coherence vanishes as soon as a single quantum is lost to the environment." (Haroche, 1998.)

Explanation of this Interpretation

I'll explain this interpretation with a specific example. The inspiration for this example, as well as my focus on objects in phase space and the effect on possibilities of impact events, came from the following simple thought experiment. Imagine two objects that are very well localized, such that a subsequent measurement of their momenta could have nearly any outcome, and then add the fact that they just impacted (and repelled) each other. This information halves their possible momenta (and thus reduces the uncertainty in their momenta) because they must be moving away from each other; the measurement of the momentum of one significantly limits the possible outcomes of a momentum measurement of the other. This fact entangles them such that no matter how far apart they are, any measurement on them will be, and obviously must be, consistent with this fact. A more thorough example follows.

Imagine N objects ($\{O_1, ..., O_N\}$), which need not be microscopic "particles," distributed in three-dimensional space discretized into M possibilities per dimension. Assume also that velocity is discretized into M possibilities per dimension. Each possible combination of location (X) and momentum (P) vectors for each and every object may be considered a single point in classical phase space, yielding a total of M^(6N) such points/possibilities. A fact (or event) is anything that reduces the number of such possibilities, so one example of a fact is an impact between two objects. Assume for simplicity that an impact between two objects is always repulsive and their masses are equal, so an impact just has the effect of swapping the objects' velocities. Assume also that an impact occurs only when two objects are at the same location at the same time; we will neglect fields.

Let us choose one set of possibilities at time T_0, specifically the set in which object O_1 has a particular position X_1 and three possible momenta P_{11}, P_{12}, P_{13}, and object O_2 has a particular position X_2 and three possible momenta P_{21}, P_{22}, P_{23}, as shown in Fig. 1 below. For the sake of demonstration, these values are chosen such that O_1 with P_{11} will, at time T_1, reach the same location in space as O_2 with P_{21}; also, O_1 with P_{12} will, at time T_2 (which may or may not be different from T_1), reach the same location in space as O_2 with P_{23}; but every other combination always results in non-coinciding future locations.

Assume there are no restrictions on the possible locations and momenta of other objects[5], so for each of the nine combinations of O_1 and O_2, there are M^[6(N-2)] possibilities involving the remaining (N-2) objects. For simplicity, let's ignore those other combinations and simply write the nine points in phase space as $\{X_1, P_{11}, X_2, P_{21}\}$, $\{X_1, P_{11}, X_2, P_{22}\}$, $\{X_1, P_{11}, X_2, P_{23}\}$, $\{X_1, P_{12}, X_2, P_{21}\}$, etc.

[5] In other words, assume no entanglements with other objects, an exceptionally unlikely situation that significantly simplifies the analysis.

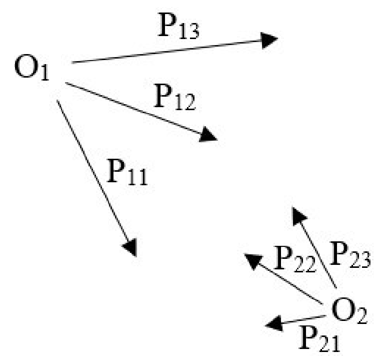

Fig. 1. Nine possibilities for two objects.

We now add the following fact about the universe: by time T_3 (which is after T_1 and T_2), O_1 and O_2 have interacted with each other but not with any other objects. (That is, they reach the same location in space and then repel, thus swapping their momenta.) Notice that this fact has the effect of reducing the number of possible combinations that can exist at T_3. Specifically, only the two possibilities, $\{X_1, P_{11}, X_2, P_{21}\}$ and $\{X_1, P_{12}, X_2, P_{23}\}$ as they existed at time T_0, can now exist at T_3. Note that at time T_3, the objects O_1 and O_2 in each of the two combinations have swapped momenta and are in different locations. For clarity, let's assume that possibilities $\{X_1, P_{11}, X_2, P_{21}\}$ and $\{X_1, P_{12}, X_2, P_{23}\}$ at time T_0 evolve, respectively, to $\{X_1', P_{21}, X_2', P_{11}\}$ and $\{X_1'', P_{23}, X_2'', P_{12}\}$ at time T_3.

This reduction in the number of combinations has two features. First, there are broad categories of individual momenta that simply cannot exist: specifically, at time T_3, O_1 cannot have a position/momentum combination that traces it back to (or is correlated to) the combination $\{X_1, P_{13}\}$ at time T_0, just as O_2 cannot be traced back or correlated to the combination $\{X_2, P_{22}\}$ at T_0, and no future measurement can contradict this.[6] Second, while other broad categories of individual momenta may not be ruled out, there are now *correlations* between the possible momenta of the objects. For example, if an evolution of O_1 from state $\{X_1', P_{21}\}$ exists at some later time, then a corresponding evolution of O_2 from state $\{X_2', P_{11}\}$ must also exist. If a future fact rules out one, then it rules out both. Similarly, if an evolution of O_1 from state $\{X_1'', P_{23}\}$ exists at some later time, then a corresponding evolution of O_2 from state $\{X_2'', P_{12}\}$ must also exist. These two objects are now entangled, no matter the distance between them.

Let me further clarify. For the moment, let's only consider the nine original possible configurations of objects O_1 and O_2. By time T_3 the only remaining possibilities are: O_1 having P_{21} *AND* O_2 having P_{11}; or O_1 having P_{23} *AND* O_2 having P_{12}. If at some later time (but before the objects have had a chance to interact with other objects), Alice measures the momentum of object O_1 to be P_{21}, it will necessarily be the case that the momentum of object O_2, if measured by Bob, would be found to be P_{11}. Even if the Alice and Bob are far apart, their measurements

[6] Note that I'm *not* asserting that an event after T_0 *retroactively* eliminates possibilities at T_0. Rather, while at T_0 there were nine possibilities, there are only two at T_3.

will be perfectly correlated. Even if the measurement events are spacelike separated – i.e., there is no fact about which measurement happens first – object O_1 having momentum P_{21} will correspond to object O_2 having momentum P_{11} and *not* P_{12}. In other words, among the nine possibilities at time T_0, the first fact (O_1 impacts O_2) eliminates all but two, and the second fact (O_1 has momentum P_{21}) eliminates one. Thus, these facts make future facts incompatible with all but one of those original nine possibilities, specifically $\{X_1, P_{11}, X_2, P_{21}\}$ at T_0.[7]

Notice that the reduction in possibilities – and the resulting correlations – have nothing to do with whether Alice or Bob knows about the correlations. I think there's been a lot of experimental research and discussion in academic journals regarding how measurements on systems with known entanglements correlate to each other, as if entanglement were some rare, almost magical quantum configuration created only in expensive labs. Instead, I think entanglement is ubiquitous. If every (or almost every) impact between objects results in a new correlation between them, then isn't every object directly or indirectly entangled with every other? If this interpretation is correct, then the universe goes on creating new facts, reducing future possibilities, and correlating the possibilities of one system with those of another, so that the possibilities for any one object depend, in some sense, on the possibilities of every other. The notion of universal entanglement is far more important, useful, and correct, I think, than has been discussed in the scientific literature.

Of course, this example is extremely oversimplified. My goal is simply to show how the quantity/density of possible combinations in phase space gets reduced by facts. For instance, as discussed above, the fact that O_1 interacts with O_2 implies that O_1 cannot have a state after T_3 that traces it back or correlates it to the state $\{X_1, P_{13}\}$ at time T_0. However, this does NOT imply that O_1 can't have momentum P_{13} after T_3. The analysis considered only a tiny (TINY!) subset of possibilities at time T_0 in which O_1 was located at X_1 and O_2 was located at X_2. To determine whether O_1 might have momentum P_{13} after T_3, we have to consider every other possible combination in which O_1 is *not* at X_1 at T_0. Looking back at Fig. 1, we can obviously move O_1 to some other location so that, with momentum P_{13}, it *does* impact O_2.

Now that I've explained the example, the primary questions I want to consider are the effects of facts on the universe in reducing the entire phase space of possibilities, and whether any interesting or large-scale pattern or structure emerges. For example, if it turned out, after several events, that O_1 having momentum P_{13} does not appear in *any* of the possible combinations at T_3, then we can state with certainty that O_1 does not have momentum P_{13} at T_3. And if in *every* possible combination after T_3 in which O_1 has momentum P_{21} we find that O_2 has momentum P_{11}, then we can say with certainty that if Alice measures the momentum of O_1 as P_{21}

[7] I don't think it matters, scientifically, whether we say that all nine combinations truly were possibilities at time T_0 and future facts narrow down possibilities when the facts occur, or that eight of the nine combinations were not actually possible at T_0 and future facts simply clarify past possibilities. The predictive power of both ideas is the same.

and Bob, who is several light-years away from Alice, measures the momentum of O_2, he will measure P_{11}.[8]

Having said all that, I think the most interesting question is: as the phase space of possibilities gets reduced in time by facts, does any structure or pattern emerge in the *distributions* of object locations and/or momenta? For example, if after lots of events involving objects O_4 and O_7, do we find, among the remaining possibilities in phase space, that the locations of O_7 relative to O_4 start to converge? If so, does the spread of the distribution (e.g., standard deviation) get tighter with the addition of subsequent facts? I suspect the answers are "yes," but have not yet done an adequate numerical analysis.

Numerical Simulation and Potential Questions

I tried programming a simulating and answering the above questions with Mathematica, but quickly realized that even the simplest possible analysis (three objects of equal mass in one dimension discretized into 10 possibilities, repeating universe, no gravity) took about 10 seconds to analyze the one million points of phase space. Imagine trying to do a more reasonable analysis of, say, 100 objects in two-dimensional space discretized to 1000 places per dimension; we're now at 1000^400 possibilities, which significantly exceeds the informational capacity of the entire universe, estimated at 10^122 bits![9] (See, e.g., Davies, 2007.)

There are a variety of mathematical tools and shortcuts that may help with the analysis. For example, I suspect that an interesting analysis could be done with a Monte Carlo simulation, essentially by just randomly selecting initial states (or, better yet, by intelligently choosing a subset of initial states from which random selections are made). We could start with a set of chronological facts/events (e.g., O_1 impacts O_5, then O_3 impacts O_9, then O_5 impacts O_6, etc.) and then run a Monte Carlo simulation to find a statistically useful set of initial states that satisfy the facts. Then, we could analyze the results to see what kind of patterns and/or localizations, if any, emerge. I suspect that after enough events, some objects would start to appear fixed relative to some other objects, and once all objects are entangled/correlated, they would all begin to show a (potentially fuzzy) localization relative to each other. Further, I suspect that this fuzziness would, as a statistical matter, decrease with increased facts (and resulting correlations). I also suspect that if we were to look at the fuzziness of, say, object O_{74}, we would find a particular spread in its location and momentum, but if we were to look only at the distribution of momenta of O_{74} in *particular* locations, we would find a larger spread. If so, then such an analysis might numerically demonstrate quantum uncertainty. Of course, I could be wrong about all this, but

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[8] So long as Alice measures after T_3 in her frame of reference but before O_1 has impacted another object and Bob measures after T_3 in his frame of reference but before O_2 has impacted another object.

[9] This should help put into perspective the insurmountable difficulties involved in doing an exact computation involving anything macroscopic. Physicists who discuss such computations invariably say misleading things like, "This calculation, which is possible in principle...". The phrase "in principle" should, in my opinion, be abolished from physics.

won't know until I can do some sort of numerical simulation or more thorough mathematical analysis.

Another question that might be answered by such an analysis is whether the times of events must be inputted (e.g., O_1 impacts O_5 at T=35 units) or whether time itself is emergent. I suspect the latter. In the previous example, O_1 having P_{21} at T_3 is correlated with O_2 having P_{11}, but it is *also* correlated with an impact at T_1, while O_1 having P_{23} at T_3 is correlated to an impact with O_2 at T_2. Thus, the later fact about the universe causes the time of the earlier impact to emerge. I suspect that when the space of possibilities specifies velocity (or momentum, as in phase space), event times are emergent; likewise, if the space of possibilities includes only locations but event times are specified, velocities would emerge.

Another issue that might be addressed by such an analysis is the relationship of objects to the underlying grid. Objects shouldn't leave the grid – i.e., space can exist without objects but not vice versa. So should objects wrap around or should a gravitational force be included that is sufficient to prevent their reaching the edge? And suddenly an analysis of quantum mechanics necessitates considerations of general relativity and the curvature of space!

Another question that might be addressed is the nature of a "fact." The above example posits a fact as the classical impact of two objects. If an analysis does not show that such facts reduce possibilities in a way that ultimately reproduces the predictions of standard quantum mechanics, are there other types of facts that do? If so, would such a finding validate this interpretation while telling us something more fundamental about the physical world, or would it simply invalidate this interpretation?

Finally, I don't have the mathematical tools to perform an analysis with continuous initial states (versus discrete states). I suspect that there is no fundamental discretization of spacetime, but rather the "resolution" of the universe increases with more facts/events. That is, there is no fundamental limit to the precision of a measurement, except to the extent that facts just don't (yet) exist to answer questions that probe beyond a certain scale. One scale, quantum uncertainty, involves a tradeoff between an object's location precision and momentum precision, while another, the Planck length, implies an energy sufficient to create a black hole if a distance smaller than the Planck length is probed. Both scales are directly related to Planck's constant.

But if every interaction between objects creates a new fact that slightly increases the universe's resolution, then Planck's constant is actually decreasing with time. In other words, it may be the case that Planck's constant is actually decreasing if it emerges from variations among possibilities, the number (or density) of which decrease with the happening of events. As Planck's constant continues to decrease, the energy of a photon at a given wavelength decreases, so shorter lengths can be probed before reaching a black-hole-inducing energy. Also as quantum uncertainty decreases (commensurate with reduction in Planck's constant), the momentum-changing kick given by that photon to probe the position of an object would have less of an effect on the measured object.

My intuition here (that spacetime is not fundamentally discretized) results from two observations. First, if there is a fixed discretization to spacetime, then the total number of possibilities is incomprehensibly large, but nevertheless finite, which means that eventually no new facts would be possible in the universe. That isn't necessarily a logical problem; hard determinists are perfectly comfortable with a single initial state evolving deterministically (i.e., without new facts) over time. But standard quantum mechanics is not deterministic, so if eventually no new facts were possible, then all future measurements would be predetermined and the randomness inherent in quantum mechanical predictions would no longer hold. My second observation is that even though I assert that each new fact only limits future possibilities (i.e., does not retroactively limit past possibilities), as in Footnote 6, one might claim that they are logically equivalent, as in Footnote 7. If eventually all facts have eliminated every possibility except one, a hard determinist might say that that single possibility, when run backward in time, identifies exactly one initial state. If that initial state includes a position and momentum for every particle, then this would violate the Kochen-Specker Theorem. If instead there were no fundamental discretization of spacetime, then every fact would have the effect of reducing the *density* of possibilities while never requiring that any object has an exact state.

Objections to this Interpretation

Implies Planck's constant is not a constant.

Maybe. (See above.) Even if it does, the time scale of this interpretation by which new facts increase the resolution of the universe (and decrease Planck's constant) is sufficiently slow that there is no reason to think that any change could have been detected in the last century, although improving measurement precision may allow this prediction to be tested in the future. One way to test this hypothesis without doing further measurements might be to retrodict the number of facts and/or entanglements that would be necessary to bring quantum uncertainty to within the scale of Planck's constant, and then determine whether the actual number of such events and/or entanglements in the universe is consistent.

In any event, despite some debate as to its implications, there is already strong evidence that correlation/entanglement within a system reduces its quantum uncertainty. (See, e.g., Rigolin, 2002.) If indeed universal entanglement correlates every object in the universe directly or indirectly to every other, it should not be surprising that increasing correlations further reduce quantum uncertainties, an hypothesis that would be verified by observing a change in Planck's constant.

Implies that the wave state Ψ is not the full description of a system.

An underlying assumption of our current understanding of quantum mechanics is that a system's wave state is its complete description, that it is a function only of position or momentum but not both, and that "the momentum wave packet for a particular quantum state [is] equal to the Fourier transform of the position wave packet for the same state." (Griffiths, Ch. 2.) These are assumptions that, so far, have provided excellent agreement with observation, but have also given rise to confusion and a variety of seeming paradoxes. Serious interpretations have been proposed that do *not* treat the wave state as complete, such as the de Broglie-Bohm pilot-wave interpretation. But perhaps quantum mechanics is not even fundamental, that it "is merely an approximation to something better." (Penrose, 2006, p. 786.) In the interpretation I'm suggesting, it may be that the current computational power of quantum mechanics is an approximation that results from the convergence of remaining possibilities after facts of the universe eliminate the vast majority. The incredible accuracy of quantum mechanics may simply be a relic of the vast number of entangling events that have occurred since the universe's beginning.

Treats objects classically.

My example in Fig. 1 treats objects macroscopically as they bounce off each other classically. The example is true of baseballs, which clearly *can* be treated classically. But that was just an example to show how facts reduce possibilities and that the remaining possibilities inherently embed evidence of those facts. That observation is essentially tautological: it must be true that impacts between systems produce facts that reduce possibilities, because otherwise what would it mean that an impact occurred? Rather, my point is that the sum and history of facts in the universe, *whatever* they consist of, are instantiated and recorded in the correlations/entanglements between objects, and give rise to (or eliminate the possibilities of) superpositions. If these facts are indeed related to phase space, as was the case in the example of Fig. 1, then these facts also localize the positions and momenta of objects relative to each other.

Requires that objects maintain identity.

This interpretation requires that objects have identity. For example, if two of the facts of the universe are that object O_9 impacts object O_4 at time T_0 and then O_4 impacts O_{12} at time T_1, then the possible locations and momenta of object O_4 after time T_1 (along with, of course, its correlations with O_9 and O_{12}) effectively embed the history of these facts. This can only be true if object O_4 at T_0 is the *same* as object O_4 at T_1 – i.e., objects must maintain their identity. However, as currently understood, many quantum mechanical objects don't have identities; they are indistinguishable in principle. For instance, if two helium nuclei (which are bosons) are exchanged in a superfluid represented by a particular wave state, then the wave state (and any predictive power we possess) will remain unchanged. How can a particular helium nucleus (and its entanglements with other objects) embed a history of facts if there's no such thing as a "particular" helium nucleus?

I'll provide several responses. First, if it turns out that the objects in question do not maintain identity, like in the above case, then there may not be a fact about one particular nucleus impacting another particular nucleus. But there may be a fact about a *group* of nuclei (for example) creating some lasting correlation in the universe, a fact that *would* be reflected in reducing possibilities. Second, the objection is based on the assumption that wave state Ψ contains all information about a system; as discussed above, this assumption may be merely a convenient approximation. Finally, entanglement and identity may be closely related; it may be the case that an object's identity determines, or is determined by, the extent to which it can be entangled with other objects. We already know that entanglement is possible between objects; what would this mean if they didn't have identity? For instance, imagine two entangled objects A and B. If object A is mixed up with lots of other "identical" objects, doesn't object A still correlate to object B? Don't objects A and B (or, perhaps, the universe as a whole) still "know" they are entangled, whether or not *we* can distinguish object A from others?

Requires nonlocality.

Yes, but so far there is no fully consistent local account of quantum mechanics, in part because standard quantum mechanics is concerned with the state of a system at an "instant" in time, a concept that conflicts with special relativity. (Maudlin, 2011, p. 111) Having said that, the interpretation I suggest does not accept standard quantum mechanics as fundamentally correct, but rather that it emerges as an excellent approximation at any particular point in *spacetime*. Consequently, I think that the only nonlocality that exists in this interpretation is that of entanglement.

For instance, in the example of Fig. 1, I showed how possibilities in phase space get reduced by the occurrence of events over time – but *whose* time? However, this question, I suspect, becomes moot once there is universal correlation (i.e., there is a correlation relationship between all objects), because the reduction in phase possibilities will proceed in a similar way from the perspective of any and every object. For instance, if O_4 impacts O_6 at a point in spacetime that is spacelike to the fact in spacetime at which O_8 impacts O_{13}, then from the perspective of O_4, its impact with O_6 will occur before the impact between O_8 and O_{13}, and vice versa from the perspective of O_8. However, O_4 and O_8 will eventually agree that both impacts occurred, and the reduction in the possible phase space will be the same.[10]

The reduction in the possible state space, as perceived from the reference of any particular object, will be experienced (and measured) exactly in accordance with the chronology of the history of facts it has witnessed. If a spacelike event occurs involving a second object, then if and when these objects directly or indirectly interact, they will agree (via measurement) on the reduction in phase space. There is no need, in this interpretation, to specify a history events at a particular point in time, but rather at a point in spacetime.

Gives no special status to superpositions.

In some sense, quantum mechanics is about nothing *but* superpositions. Even a nice pure position eigenstate is equivalent to a summation over infinitely many momentum harmonics. In sharp contract, the interpretation I'm suggesting gives special status to facts and relegates superpositions to the leftovers: "A superposition just means there's no relevant fact. Yet."

[10] This solution to the problem of special relativity is reminiscent of the approach taken by Relational Quantum Mechanics, whereby the state of a system is akin to the summing of individual correlations between objects – i.e., an object only has a state relative to another object. (See, e.g, Rovelli, 1996.) However, I think the primary benefit of relational QM is to (attempt to) resolve the Wigner's Friend problem while still embracing the truth of the wave function, but still offers no explanation for or clarity in *understanding* the wave function.

But physics should never have given superpositions such a mighty status. Note the interesting fact that it is possible for a single measurement to confirm a superposition does not exist, but there is no single measurement that can *ever* confirm that a superposition does exist.[11] Rather, superpositions are seen only when interference effects are observed in experiments involving many "identically prepared" particles (or objects or whatever). But can we be sure that lots of particles can be identically prepared? No. It is already known that the de Broglie-Bohm pilot-wave description is a hidden-variables deterministic model that accurately reproduces most predictions of quantum mechanics, while asserting that a particle in a double-slit experiment is *not* in a superposition of passing through both slits (even if the wave function itself is). Rather, the appearance of interference in a double-slit experiment, according to Bohm, is due to the different initial positions of particles prior to the experiment; thus Bohm denies that such particles are actually identically prepared.

[11] Not to be overly technical, but it actually takes infinitely many experiments to confirm a superposition.

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