Macroscopic Quantum Superpositions Cannot Be Measured, Even in Principle

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(Dated: August 25, 2020)

I show in this paper why the universality of quantum mechanics at all scales, which implies the possibility of Schrödinger's Cat and Wigner's Friend thought experiments, cannot be experimentally confirmed, and why macroscopic superpositions in general cannot be observed or measured, even in principle. Through the relativity of quantum superposition and the transitivity of correlation, it is shown that from the perspective of an object that is in quantum superposition relative to a macroscopic measuring device and observer, the observer is already sufficiently well correlated to the measuring device that once the object correlates to the measuring device, there is no time period in which the observer can perform an appropriate interference experiment to show that the measuring device is in a superposition.

Setting aside that Schrodinger himself introduced his hypothetical cat specifically to point out the absurdity of treating his linear, deterministic equation as applying universally, there is no shortage of academic literature that treats Schrodinger's Cat (and its conscious cousin, Wigner's Friend) as possible in principle, even if difficult or impossible for all practical purposes [1–15]. The viability of the Schrodinger's Cat ("SC") and Wigner's Friend ("WF") thought experiments, and the in-principle possibility of macroscopic[1] quantum superpositions in general, depend on the existence of some nonzero time interval in which the wave state of an observer has not yet entangled with that of a macroscopic system in superposition, allowing the observer (in a properly designed experiment) to measure the macroscopic system in a basis[2] that confirms interference effects.

This will be shown to be incorrect. The preexisting entanglements between the observer and macroscopic system guarantee that such a time interval is actually zero, preventing the in-principle possibility of experimentally confirming the existence of a macroscopic quantum superposition. This conclusion will follow whether quantum mechanics is universally valid or quantum wave states instead undergo nonlinear collapses. For the sake of argument, I will assume the universality of quantum wave state evolution.

In Fig. 1, an object O is inside container C in a superposition over states $|A\rangle$ and $|B\rangle$ that are semiclassically localized at distinct positions A and B, separated by distance d, so that its initial state can be written as $|O\rangle = \frac{1}{\sqrt{2}}(|A\rangle + |B\rangle)$.[3] Inside container C is a measuring device M configured to measure (through the process of interacting with and correlating to) the object O, as well as Wigner's Friend F, who is ready to observe the macroscopic output of the measuring device M. Outside the box is observer Wigner W, who set up the experiment so that at time t_0 he is informationally isolated from the container C.[4] At time t_1, the device M measures the object's position; at t_2, friend F observes the output of the device M; at t_3, observer W ends his information isolation from container C and opens container C to discover what output friend F observed.

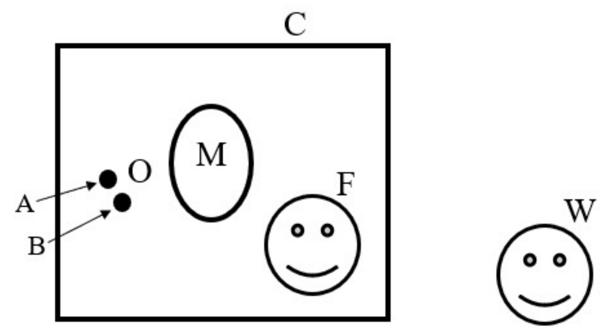

FIG. 1. An object O in quantum superposition over states that are semiclassically localized at positions A and B relative to measuring device M and Wigner's Friend F enclosed within container C that is informationally isolated from external observer Wigner W.

[1] The meaning of the word "macroscopic" will become clearer later in this paper, but suffice it to say that it includes anything that can be seen with the naked eye, such as a dust particle, a cat, or a human.

[2] A pure state represented as an eigenstate in one basis may be represented as a superposition in a different basis. For clarity, unless otherwise indicated, the word "superposition" in this paper will refer to superposition in the position basis without loss of generality.

[3] Note that for $|A\rangle$ and $|B\rangle$ to be measurably distinct states, distance d should be on the same or larger order of magnitude than the diameter of object O. For instance, if object O is a C_{60} molecule, then a realistic value of d should exceed 1nm.

[4] Whether such isolation is actually possible is certainly debatable. Proponents of the viability of SC/WF assume that isolating observer W from the rest of the system starting at time t_0, so that observer W is not privy to information correlating his state with that of the macroscopic system inside container C, is adequate to allow observer W, in principle, to measure interference effects of that macroscopic system in superposition. This will be shown to be false. Therefore, for the sake of argument, I'll concede the possibility that information isolation between observer W and container C (and its contents) is possible for some arbitrary time period.

Let $|M_0\rangle$ be the initial state of the device M, $|M_A\rangle$ the macroscopic state to which the device M is configured to evolve over time if it measures the object O in position A, etc. Neglecting normalization constants, the universality of quantum mechanics implies the following von Neumann-style measurement chain:

$$\begin{aligned} & |O\rangle \Big(|M_0\rangle |F_0\rangle |W_0\rangle\Big) \\ = & \Big(|A\rangle + |B\rangle\Big)\Big(|M_0\rangle |F_0\rangle |W_0\rangle\Big) \\ \xrightarrow{t_1} & \Big(|A\rangle |M_A\rangle + |B\rangle |M_B\rangle\Big)\Big(|F_0\rangle |W_0\rangle\Big) \\ \xrightarrow{t_2} & \Big(|A\rangle |M_A\rangle |F_A\rangle + |B\rangle |M_B\rangle |F_B\rangle\Big)\Big(|W_0\rangle\Big) \\ \xrightarrow{t_3} & |A\rangle |M_A\rangle |F_A\rangle |W_A\rangle + |B\rangle |M_B\rangle |F_B\rangle |W_B\rangle \end{aligned} \quad (1)$$

If Eq. 1 is correct, then there exists a nonzero time interval $(t_3 - t_2)$ in which the observer W can in principle, through an appropriately designed interference experiment, confirm that the system inside the container C is in a macroscopic superposition relative to him. However, this will now be shown to be false because observer W is already, through past interactions, adequately correlated to the system inside the container C so that no experiment after time t_1 will allow observer W to demonstrate interference effects.

Before proceeding, it should be clarified that the state of object O, written as a superposition over localizations at positions A and B, depends on the meaning of "position." Because there are no preferred frames of reference in spacetime, the locations of positions A and B only have meaning with reference to other objects. In Fig. 1, positions A and B are localized relative to the other objects shown, such as the device M, container C, observer W, etc. But which one? In the present case, it doesn't matter, but for reasons that may be underappreciated.

Quantum uncertainty ensures that infinite precision in the relative locations of objects cannot exist, resulting in a "fuzziness" by which the locations of A and B relative to container C necessarily differ, albeit slightly, from the locations of A and B relative to observer W. Natural quantum dispersion of wave packets would, unabated, continually increase the relative fuzziness between objects. However, such dispersion does not, in our actual universe, grow unabated. The universe is full of particles and fields that constantly interact with objects to decohere their relative superposition coherence; the larger the objects, the more quickly relative superpositions decohere [2]. For instance, Ref. [1] calculates coherence lengths (roughly "the largest distance from the diagonal where the spatial density matrix has non-negligible components") for a $10\mu m$ dust particle and a bowling ball caused by various decoherence sources, as shown in Table I. Even in deep space, cosmic microwave background ("CMB") radiation alone will localize the dust particle to a dimension many orders of magnitude smaller than its diameter.

TABLE I. Some values of coherence lengths for a $10\mu m$ dust particle and a bowling ball caused by various decoherence sources, given by [1].

Decoherence source	$10\mu m$ dust	Bowling ball
300K air @ 1 atm	$10^{-17}m$	$10^{-21}m$
300K air in lab vacuum	$10^{-13}m$	$10^{-18}m$
Sunlight on Earth	$10^{-12}m$	$10^{-17}m$
300K photons on Earth	$10^{-12}m$	$10^{-16}m$
CMB radiation	$10^{-8}m$	$10^{-14}m$
Solar neutrinos	n/a	$10^{-13}m$

Therefore, in Fig. 1, whether or not the locations of A and B must be specified relative to container C *or* observer W would matter only if the quantum fuzziness between C and W was significant relative to distance d. However, given that the coherence length for a bowling ball due to ubiquitous CMB radiation is on the order of $10^{-14}m$, the quantum fuzziness between C and W can never be more than $10^{-14}m$, even if we neglect all decoherence sources except CMB.[5] Therefore, the locations of A and B (as well as state $|O\rangle = \frac{1}{\sqrt{2}}(|A\rangle + |B\rangle)$) are insensitive to whether specified relative to C, W, etc., for any realistic value of d.

In other words, state $|O\rangle$ can be specified relative to C, W, etc., without loss of generality, because these macroscopic objects are already well-correlated to each other with relative coherence lengths that are insignificant (relative to d). However, it logically follows that if these macroscopic objects were *not* well correlated, then the state of the object O would depend heavily on its specification relative to one object or another – that is, quantum superpositions are inherently and necessarily relative.[6]

In Fig. 2, the system of Fig. 1 is shown relative to, or from the perspective of, object O, with locations of various positions MA, MB, FA, FB, etc., specified relative to object O. Thus, at time t_0, the system (consisting of M, F, etc.) is in a superposition relative to object O.

Let $|M^{MA}\rangle$ be the state of the device M localized at position MA, $|M^{MB}\rangle$ be the state of the device M localized at position MB, and so forth. Combining this

[5] The notion of shielding one or both from CMB to allow quantum fuzziness to grow to something significant is a logical nonstarter, as it assumes the very conclusion this paper attempts to disprove. If amplification cannot convert a superposition of object O into a measurable superposition of a macroscopic object (e.g., container C) to which it is correlated, then surrounding that macroscopic object by an even *larger* macroscopic object for the purpose of "shielding" does not solve the problem.

[6] While I take it as logically necessary that translational invariance demands the relativity of quantum superpositions, the concept is still somewhat new [16–18].

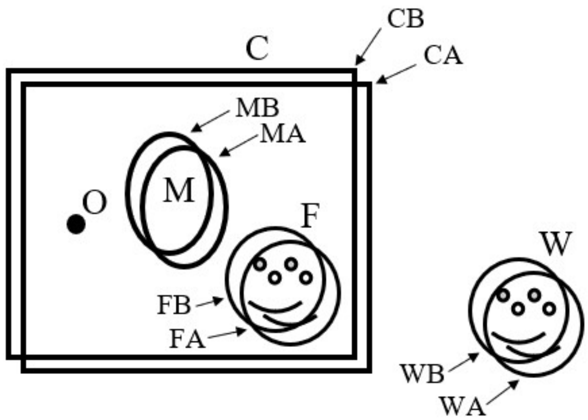

FIG. 2. Physically identical to the scenario shown in Fig. 1, measuring device M is in quantum superposition over states that are semiclassically localized at positions MA and MB relative to object O, friend F is in superposition over positions FA and FB relative to object O, and so forth.

nomenclature with that of Eq. 1, state $\left|F_0^{FA}\right\rangle$, for example, represents the state of friend F who is localized (relative to object O) at position FA and who has not yet evolved (via amplification over time) to a state in which he has observed device M indicating the location of object O at position A, while $\left|F_A^{FA}\right\rangle$ represents the state of friend F who *has* so evolved. Thus, neglecting normalization constants, the system evolves relative to object O and starting at time t_0 as follows:

$$\begin{aligned}
&|O\rangle \left(\left|M_0^{MA}\right\rangle \left|F_0^{FA}\right\rangle \left|W_0^{WA}\right\rangle \right.\\
&\quad \left. + \left|M_0^{MB}\right\rangle \left|F_0^{FB}\right\rangle \left|W_0^{WB}\right\rangle\right)\\
\xrightarrow{t_1}\ & \left|O^A\right\rangle \left|M_A^{MA}\right\rangle \left|F_0^{FA}\right\rangle \left|W_0^{WA}\right\rangle\\
&\quad + \left|O^B\right\rangle \left|M_B^{MB}\right\rangle \left|F_0^{FB}\right\rangle \left|W_0^{WB}\right\rangle\\
\xrightarrow{t_2}\ & \left|O^A\right\rangle \left|M_A^{MA}\right\rangle \left|F_A^{FA}\right\rangle \left|W_0^{WA}\right\rangle\\
&\quad + \left|O^B\right\rangle \left|M_B^{MB}\right\rangle \left|F_B^{FB}\right\rangle \left|W_0^{WB}\right\rangle\\
\xrightarrow{t_3}\ & \left|O^A\right\rangle \left|M_A^{MA}\right\rangle \left|F_A^{FA}\right\rangle \left|W_A^{WA}\right\rangle\\
&\quad + \left|O^B\right\rangle \left|M_B^{MB}\right\rangle \left|F_B^{FB}\right\rangle \left|W_B^{WB}\right\rangle \qquad (2)
\end{aligned}$$

At initial time t_0, while $\left|W_0^{WA}\right\rangle$ is correlated to $\left|F_0^{FA}\right\rangle$ and $\left|M_0^{MA}\right\rangle$, none of them are correlated to $|O\rangle$, which would allow them (in conjunction) to perform an interference experiment to show that object O is in a superposition relative to them. This also is true of $\left|W_0^{WB}\right\rangle$ (who is correlated to $\left|F_0^{FB}\right\rangle$ and $\left|M_0^{MB}\right\rangle$). Thus, object O is, not surprisingly, in a superposition relative to every possible observer W at time t_0.

However, at time t_1, measurement of the system by the object O (or, equivalently, measurement of the object O by device M) results in a correlation between object O and the rest of the system so that $\left|W_0^{WA}\right\rangle$, $\left|F_0^{FA}\right\rangle$, and $\left|M_0^{MA}\right\rangle$ become correlated to $\left|O^A\right\rangle$ and vice versa for $\left|O^B\right\rangle$. Therefore, $\left|W_0^{WA}\right\rangle$ is now correlated to $\left|O^A\right\rangle$ via shared entanglements with $\left|F_0^{FA}\right\rangle$ and $\left|M_A^{MA}\right\rangle$. As a result, $\left|W_0^{WA}\right\rangle$ is not in a superposition relative to the object O because he would, with certainty, find object O located at position A relative to him. Indeed, he *will* find that, through amplification over time as $\left|W_0^{WA}\right\rangle$ evolves to $\left|W_A^{WA}\right\rangle$, but my point is that the superposition of object O relative to $\left|W_0^{WA}\right\rangle$ (and $\left|W_0^{WB}\right\rangle$) has already disappeared by time t_1 because of the event that correlates $\left|O^A\right\rangle$ with $\left|M_0^{MA}\right\rangle \left|F_0^{FA}\right\rangle \left|W_0^{WA}\right\rangle$ and $\left|O^B\right\rangle$ with $\left|M_0^{MB}\right\rangle \left|F_0^{FB}\right\rangle \left|W_0^{WB}\right\rangle$. In other words, there is no time period after t_1 in which observer W (represented as either $\left|W^{WA}\right\rangle$ or $\left|W^{WB}\right\rangle$) can perform an interference experiment on object O to demonstrate a superposition.

In fact, there was *never* a time at which observer W was sufficiently uncorrelated to device M or friend F to allow him to measure them in a superposition. In Eq. 2, $\left|W^{WA}\right\rangle$ is *always* correlated with $\left|M^{MA}\right\rangle$ and $\left|F^{FA}\right\rangle$, thanks to past interactions (prior to t_0) that ensured that W, F, and M (as well as container C) are well correlated with each other. Even if an appropriate experiment could demonstrate object O in superposition relative to them at time t_0 (with that opportunity ending upon correlation of object O with the system at time t_1), no experiment by observer W could *ever* demonstrate device M or friend F in superposition relative to him. Amplification over time does not make possible what is otherwise impossible in principle. After the object O becomes correlated to the device M at time t_1, subsequent amplification only increases the magnitude of correlations but never produces an observer W that is uncorrelated to the location of object O relative to him.

Even though no wave state reduction is shown or assumed in Eq. 2, from the perspective of observer W, the wave state of the system has *apparently* collapsed at time t_1, with neither observer $\left|W^{WA}\right\rangle$ nor $\left|W^{WB}\right\rangle$ capable, even in principle, of demonstrating a superposition of object O (or device M or friend F). Importantly, once device M entangles with object O at time t_1, the inability of observer W to empirically demonstrate a superposition involving O, M, or F (or C) has nothing to do with his technological limitations – instead, there is never a time after t_1 at which such a superposition *exists* relative to him. Even prior to time t_1, preexisting correlations between M, F, C, and W guarantee that at no time is observer W in a superposition relative to the other macroscopic objects that exceeds some entirely inconsequential relative coherence length. Thus, observer W can never demonstrate *any* macroscopic system to be in a quantum superposition because, relative to him, it never is. Amplification via the von-Neumann-type chain in Eq. 1 does not circumvent this impossibility, nor does hypothetical information isolation between W and other macroscopic objects.

So what's wrong with Eq. 1? The conventional mistake in its interpretation (leading to the belief that amplification can produce a superposition of device M or friend F relative to observer W) is assuming that macroscopic measuring subsystems do not correlate to an object in superposition until *after* they evolve into their respective macroscopic pointer states. For instance, even though friend F will not observe the macroscopic output of the device M until t_2, at which time he will evolve into a macroscopic state that is correlated to that observation, it is incorrect to state that he is uncorrelated to object O at time t_1. Instead, because friend F is already well correlated to device M, the transitivity of correlation[7] logically requires that when device M becomes well correlated with object O at time t_1, friend F simultaneously becomes well correlated to object O. The same is true for observer W, who was already well correlated to friend F at time t_1.

Some implications of the above analysis will now be briefly discussed.

Quantum mechanics is not verifiably universal. Whether or not quantum mechanics is universally valid is often regarded as an open question which can, in principle, be answered empirically with a property devised experiment [9]. However, the above analysis shows that no experiment can demonstrate or verify the existence of a macroscopic quantum superposition, and further that there is no time period in which two macroscopic objects are in superposition relative to each other. Indeed, from the perspective of every observer W, the wave state of an observed system actually or apparently collapses long before a superposition can become macroscopic. Because no experiment can, even in principle, demonstrate a macroscopic superposition, whether quantum mechanics is universally applicable to all systems is a non-scientific question.

The Many Worlds Interpretation ("MWI") is not testable. It might be argued that the states shown in Eq. 2 indicate "many worlds" of observers who observe different outcomes to measurement events, whereby observed collapse of the wave function by each of observers $\left|W_A^{WA}\right\rangle$ and $\left|W_B^{WB}\right\rangle$ is only *apparent* and not real. I have indeed assumed the universality of quantum mechanics for the sake of analysis and to avoid having to explain away nonlinear collapses. However, whether or not W's observation of collapse is merely apparent, it should be emphasized that after time t_1, observer W (in whatever form) cannot perform any experiment, even in principle, that would show a superposition of device M or friend F. Whether or not the universe as a whole is continually in a coherent superposition as observed by some "superobserver" external to the entire universe, such a notion would conflict with MWI as a testable scientific theory.

Heisenberg cut. The "Heisenberg cut" above which quantum interference effects can no longer be detected in practice is limited by its coherence length due to constant interactions with decoherence sources throughout the universe. However, the above analysis shows that this division between the microscopic and macroscopic worlds is not merely a "FAPP" limitation, with quantum mechanics applying universally in principle. Instead, when an object in quantum superposition entangles with a macroscopic object, no observer can empirically determine that the macroscopic object is in a superposition, even in principle, because there is no time at which such a relative superposition exists.

Macroscopic quantum superpositions (including SC/WF experiments) are impossible in principle. Existing (i.e., past) entanglements between macroscopic objects so well localize them relative to each other that entanglement of one of the macroscopic objects with a tiny object in quantum superposition instantly entangles them all. In Eq. 2, once object O entangles with device M at time t_1, it simultaneously entangles with observer W (as well as the rest of the universe, to which observer W was already well correlated). In other words, due to existing entanglements that strongly correlate the observer W with the measuring device M, the device's measurement of object O will "instantly" correlate object O to observer W, leaving observer W no time in which to empirically confirm a macroscopic superposition of measuring device M. The only way to avoid this simultaneous entanglement between object O and observer W would be if device M and observer W were not already well correlated – specifically, if the quantum "fuzziness" between M and W were significant relative to the distance d between positions A and B. However, interactions with particles and fields bathing the universe guarantee that the coherence length of even the tiniest visible speck of dust is less than any d that could distinguish states $|A\rangle$ and $|B\rangle$. Thus, there is no time, even in principle, in which a measuring device M is, or can be measured, in a superposition relative to observer W. Further to this conclusion, neither SC nor WF (as macroscopic objects) are possible, even in principle.

CCCH is false. The hypothesis that consciousness causes collapse ("CCCH") of the quantum wave state finds its roots in Eq. 1. Essentially, proponents argue that observer W does indeed measure a (collapsed) outcome, such as $|A\rangle\,|M_A\rangle\,|F_A\rangle$, and since there is no way to confirm that an outcome has been measured except ultimately via the observation of a conscious person, then the collapse may have literally been caused by the conscious observation [5, 19]. Of course, the Wigner's Friend thought experiment complicates matters – does friend F

[7] Although I am not aware of the notion of "transitivity of correlation" in the academic literature, it both implies and is implied by the nonlocal entanglement described by Einstein as "spooky action at a distance." If a subsystem contains its own correlations, such as a two-particle system having opposite momenta, then measurement of one particle correlates it to the rest of the universe; this necessarily implies correlation of the second particle to the rest of the universe, a fact that can be verified by spacelike measurement of that second particle. The nonlocal "simultaneity" of quantum entanglement seems less spooky when expressed in terms of the transitivity of correlation: the measurement of system B by system A merely instantiates, relative to system A, the correlations that already existed in system B.

collapse the wave function or does the observer W? In any event, CCCH requires both a nonlinear collapse as well as consciousness as its cause. While the above analysis does not assume collapse, it shows that if there *is* a collapse of the wave function of an object in quantum superposition, then it happens when an event correlates that object with *any* macroscopic object (i.e., one exceeding the Heisenberg cut, a designation that includes even the tiniest visible particle). Because conscious observations depend on correlations to macroscopic body parts (e.g., sensory organs), a collapse of a quantum superposition, if it occurs, must happen long before a person's conscious awareness.

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