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RESOLUTION OF THE PROBLEM OF DEFINITE OUTCOMES

Art Hobson

Department of Physics, University of Arkansas
Fayetteville, AR, 72701, US.
Corresponding author; E-mail: ahobson@uark.edu

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Abstract: This paper resolves the problem of definite outcomes, also known as "Schrodinger's cat" and the "problem of wavefunction collapse." It's the problem of understanding how nature goes from a coherent superposition of possible outcomes to a single definite outcome. This "measurement problem" has not to my knowledge been solved. The analysis stems from an insight into entanglement demonstrated in two nonlocality experiments involving pairs of momentum-entangled photons. These show that an entangled state of two subsystems is not a superposition of products of paired *states*, but instead a superposition of *correlations between paired states.* The "premeasurement state" is just such a superposition with the proviso that one subsystem is the detector of the other subsystem. This state is not a paradoxical superposition of macroscopic detector states; it is instead a superposition of *correlations between detector states and microscopic quantum states*. Thus, Schrodinger's cat isn't "smeared" between dead and alive but instead represents a nonlocal superposition of *correlations between* states of the cat and states of the nucleus: This is what we want. We also critique one previously claimed resolution of the measurement problem and seven previously claimed proofs that the measurement problem is unsolvable.

Keywords: quantum measurement problem, problem of outcomes, entanglement, nonlocality, Schrodinger's cat, wave function collapse.

INTRODUCTION

This analysis demonstrates that the problem of definite outcomes arises from a technical misunderstanding of entanglement and nonlocality. A proper understanding resolves the problem.

Since entangled states play a central role in most formulations of the measurement problem, and since entanglement is generally associated with non-local action (HOBSON, 2024), this paper investigates connections between nonlocality and measurement. We review two 1991 experimental investigations of entangled photons that are remarkable for being the only nonlocality tests (tests of Bell's inequality) based on mechanical variables (namely photon

ORCID: A. Hobson - 0000-0002-8312-0977

momenta) rather than quantum variables such as spin (RARITY and TAPSTER, 1990; OU *et al.*, 1990). We show that a proper understanding of entanglement and nonlocality resolves the problem of definite outcomes.

Section 2 reviews one of the most common formulations of the measurement problem, namely the "problem of outcomes" or "Schrodinger’s cat." Briefly, the problem is that the premeasurement entangled state seems to describe a macroscopic measurement device that simultaneously exhibits all possible measurement outcomes, even if those outcomes are "dead cat" and "alive cat." Such a macroscopic superposition is absurd (SCHRODINGER, 1935).

Section 3 reviews another common formulation of the measurement problem, first described by Einstein at the 1927 Solvay Conference (GILDER, 2008; KUMAR, 2008; BACCIAGALUPPI *et al.*, 2009). This is the "collapse of the wave function" that occurs when a single quantum object such as an electron is described by a dynamically evolving spatially extended wave function that interacts with a detection device such as a viewing screen, causing the wave function to instantaneously collapse into a far more compact region. As Einstein noted, this appears to violate special relativity.

Section 4 presents the experimental background for properly understanding the measurement problem. We examine two quantum optics experiments that demonstrate nonlocal action between two momentum-entangled photons (RARITY and TAPSTER, 1990; OU *et al.*, 1990).

Section 5 utilizes this understanding of nonlocal action to resolve the problem of outcomes.

Similarly, Section 6 resolves the puzzle of wave function collapse.

Section 7 shows that a well-known presumed resolution of the measurement problem (GOTTFRIED, 1966, 1991; GOTTFRIED *et al.*, 1991) has a fatal flaw.

Section 8 disproves seven presumed proofs (WIGNER, 1963; D'ESPAGNAT, 1966; FINE, 1970; SHIMONY, 1974; BROWN, 1986; BUSCH and SHIMONY, 1996; BACCIAGALUPPI, 2013) of the insolvability of the measurement problem.

Section 9 summarizes this paper’s conclusions.

The Problem of Outcomes ("Schrodinger’s Cat")

First posed by E. Schrodinger and known as "Schrodinger’s Cat" (SCHRODINGER, 1935) this formulation of the measurement problem is also known as the "problem of outcomes" (SCHLOSSHAUER, 2007). Consider a quantum system A having (for simplicity) a two-dimensional Hilbert space spanned by orthonormal states |A1> and |A2> and let O be the observable whose eigenstates are |A1> and |A2>. A "detector" D of O must contain a quantum component having the following three quantum states: |Dready,> represents a state in which D is poised to detect whether A is in state |A1> or |A2>, and |Di> (i=1 or 2) represents macroscopic registration that A was detected in the state |Ai>. D must also have a component that amplifies the microscopically detected outcome to irreversibly register that outcome, perhaps by creating a visible mark or an audible click. Thus, D is a macroscopic object with a quantum component.

For example, A might be a single electron passing through a double-slit setup containing a viewing screen, with "which-slit detectors" D1 and D2 present at both slits. The states |Di> (i=1 or 2) then represent the "clicked" state of the first or second detector. Suppose that, before measurement, A is prepared in an eigenstate |Ai> (i=1 or 2). A minimally disturbing measurement is then represented by

|Ai> |D ready> ==> |Ai> |Di>   (i = 1, 2)   (1)

where |*Ai*> represents the premeasurement eigenstate, the arrow represents the measurement process, and the right-hand side represents the post-measurement state. Note that the same state $|Ai>$ appears on both sides of (1), i.e. we assume that, when *A* is prepared in an eigenstate of ***O,*** measurement of ***O*** does not disturb that eigenstate. This is an idealization.

Now suppose *A* is prepared in a 50-50 superposition of its eigenstates:

$$|Y_A> = \frac{(|A1> + |A2>.}{\sqrt{2}} \tag{2}$$

It follows from the linearity of the time evolution that a "which state" measurement of *A* is then represented by

$$\frac{(|A1> + |A2>)}{\sqrt{2}} |D\ ready> ==> |Y_{AD}> \tag{3}$$

where $|Y_{AD}>$ is defined as

$$|Y_{AD}> = \frac{|A1> |D1> + |A2> |D2>}{\sqrt{2}} \quad . \tag{4}$$

A similar enigmatic entangled state crops up in nearly every analysis of the measurement problem. Following Schlosshauer (SCHRODINGER, 1935), we will call it the "premeasurement state."

The observed result of such a "measurement" ("detection" would be a more accurate word) is known from experiment to be

outcome $|Di>$ is found with 50% probability (*i=1 or 2).* (5)

Equation (4) does not appear to be equivalent to (5). This is known as the “problem of outcomes." As one expert aptly put it, "The problem of what to make of this" (namely the state (4)) "is called ‘the measurement problem’" (MYRVOLD, 2022).

Equation (4) seems to represent a superposition of two detector states. In the case of an electron passing through a double slit experiment with detectors at both slits, (4) appears to describe one electron that passes through both slits, causing both detectors to click. This is not allowed because of Max Planck’s quantization postulate: Energy is always "found" in discrete finite lumps, with each lump having energy $E = hf$. This is of course the fundamental quantum postulate.

The symmetry of the above example implies that, classically, the energy passes in equal amounts through both slits, hence energy *(hf/2)* passes through each slit. Equation (5), which is an experimental fact, then leads naturally assumption that each term should be treated in a probabilistic sense, implying that $<Y_{AD}|Y_{AD}>$, evaluated at the ith detector, represents the probability that the photon will register at the i^{th} detector (i= 1, 2) – the Born rule.

In 1935, Schrodinger wrote a long philosophical paper published in three issues of *Die Naturwissenschafter (The Natural Sciences)* laying out his views on quantum foundations (GILDER, 2008). His infamous cat is mentioned in only two brief paragraphs within a Section titled "are the variables in fact smeared out?" (i.e.are the subsystems *A* and *D* described by a phase-dependent superposition?).

Schrodinger gets to the heart of the matter in his example of a "very burlesque case" of "smearing." He imagines a cat locked up in a closed room together with a radioactive sample placed in a radiation detector in such a manner as to create a 50-50 chance of a radioactive decay triggering the detector within one hour. Such triggering would activate a macroscopic device that would kill the cat. Schrodinger states, "in terms of the *y* function of the entire system, this will be expressed as a mixture [today we would call it a "superposition"] of a living and dead cat." He notes that "a microscopic uncertainty has been transformed into a coarse grained (macroscopic) uncertainty." Such a macroscopic quantum superposition of a state in which the cat is dead (and the radiation detector has clicked) and a state in which the cat is alive (and the detector has not clicked) would be absurd.

Let's return to (4), which represents a superposition of two states of the compound system *AD*. Those two states are represented by the two dyads $|Ai> |Di> (i = 1, 2)$. For example, in the electron 2-slit experiment with detectors at both slits, the conventional interpretation of (4) would be "In a single trial, the electron was detected at the first slit AND the electron was detected at the second slit." This describes an absurd superposition of two macroscopic outcomes. What's wrong?

Prior to answering this question (Section 5), we present a second version of the problem of definite outcomes (Section 3). Section 4 will then present two experiments that provide insight into these problems.

The Problem of Wave Function Collapse

Einstein, at the 1927 Solvay Conference on Electrons and Photons, was the first to point out the conundrum now known as "collapse of the wave packet." In an impromptu remark late in the conference, he asked the audience to consider a thought experiment in which an electron passes through a tiny hole in an opaque screen and then impacts a large hemispherical detection screen centered at the hole (see Fig. 1) (GILDER, 2008; KUMAR, 2008; BACCIAGALUPPI *et al.*, 2009).

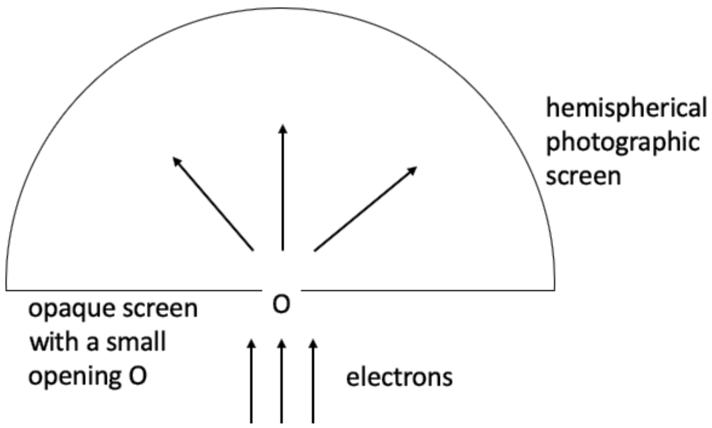

Figure 1: Einstein's thought experiment.

On each trial, a single electron diffracts widely, and then simultaneously arrives at every point on the hemispherical screen. Yet only one point registers an impact! How do the other points *instantaneously* remain dark? This appears to violate special relativity.

According to Schrodinger's equation, each electron diffracts widely after passing through the opening. A short time later, the entire electron (i.e. the entire wave function) interacts symmetrically with the *entire screen*. Because of the screen's hemispherical shape, this occurs *at a single instant*. Yet each electron registers at only a single point! How do the other points remain dark? Why don't they also register an impact? After all, the same wave function arrives simultaneously at every point on the screen.

As Einstein writes in his notes, "this entirely peculiar mechanism of action at a distance, which prevents the wave continuously distributed on the screen from producing an effect in *two* places on the screen" presents a problem. How do the points that do *not* show an impact *instantly* "know" that they should remain dark? Einstein thought an instantaneous signal must "inform" these points that the impact occurred elsewhere. Such a signal would violate special relativity.

Experiments with momentum-entangled photons

Two quantum optics experiments (RARITY and TAPSTER, 1990; OU *et al.*, 1990) published nearly simultaneously in 1991 demonstrate that the conventional interpretation of the premeasurement state (4) is incorrect, and that (4) is in fact precisely what we want and expect during a measurement. We shall call these experiments the "RTO experiments", honoring the two authors of the first report and the lead author of the second report.

RTO investigated entangled momentum states of two photons. Labeling the first photon "*A*" and the second photon "*B",* this entangled state was

$$|Y_{AB}> = \frac{|A1> |B1> + |A2> |B2>}{\sqrt{2}} \qquad (6)$$

where $I|Ai>$ $(i=1,\ 2)$ represents two orthonormal momentum eigenstates of the first photon and $I|Bi>$ $(i = 1,\ 2)$ represents two orthonormal momentum eigenstates of the second photon. Equation (6) is isomorphic to (4) with the important distinction that, in (6), both subsystems are microscopic. As we shall soon see, the entangled state (6) has non-local properties.

2022 Physics Nobel laureate Alain Aspect has remarked (PHILLIPS and DALIBARD, 2023) that the RTO experiments were unique because they were and are the only investigation of entangled *mechanical* degrees of freedom, namely linear photon momenta. All other entanglement experiments, including Aspect's prize-winning experiment, investigated photon polarization states.

Fig. 2 shows the layout for the RTO experiments. Two photons *A* and *B* were entangled by down-conversion of a single high-frequency photon. In Fig. 2, this entanglement is presumed to occur within the "source", so the photons were in the entangled state (6) as they emerged from the source. Photon *A* emerged moving along two paths A1 and A2, while *B* emerged moving along two other paths B1 and B2. Variable phase shifters f_A and f_B were inserted into one of *A*'s two paths and one of *B*'s two paths, respectively. We label these phase shifts f_A and f_B.

Remarkably, *neither photon Interfered with itself as a function of its own phase* f_A or f_B. That is, *individual photons were incoherent rather than phase-dependent or "smeared*:" Regardless of the phase settings f_A and f_B,

$$P(A1) = P(A2) = P(B1) = P(B2) = 0.5 \qquad (7)$$

This incoherence must be attributed to the entanglement.

However, coherence had not vanished. RTO found that the expected coherence of each photon had instead shifted: A and B now interfered with each other (rather than with themselves) as a function of the difference fA-fB of the two phase angles: When the experimenters shifted this "nonlocal phase difference" to various angles between 0 and 180 degrees, the correlation between the two photons varied as shown in Fig. 3.

Fig. 3 represents a remarkable new natural principle: When a composite system AB with microscopic sub-systems A and B becomes entangled, the pre-entanglement coherence of the subsystems is transferred to the new composite system. That is, the subsystems lose their coherence while the correlation between A and B becomes coherent or "smeared" (phase-dependent).

Indeed, Rarity and Tapster's outcomes at the four detectors violate Bell's inequality, verifying the nonlocality. Ou et al. were unable to demonstrate a violation of Bell's inequality. They state that "although experiments to demonstrate violations of Bell's inequality would require higher visibility of the interference, we have nevertheless confirmed the principle of two-photon interference under conditions of very great path difference."

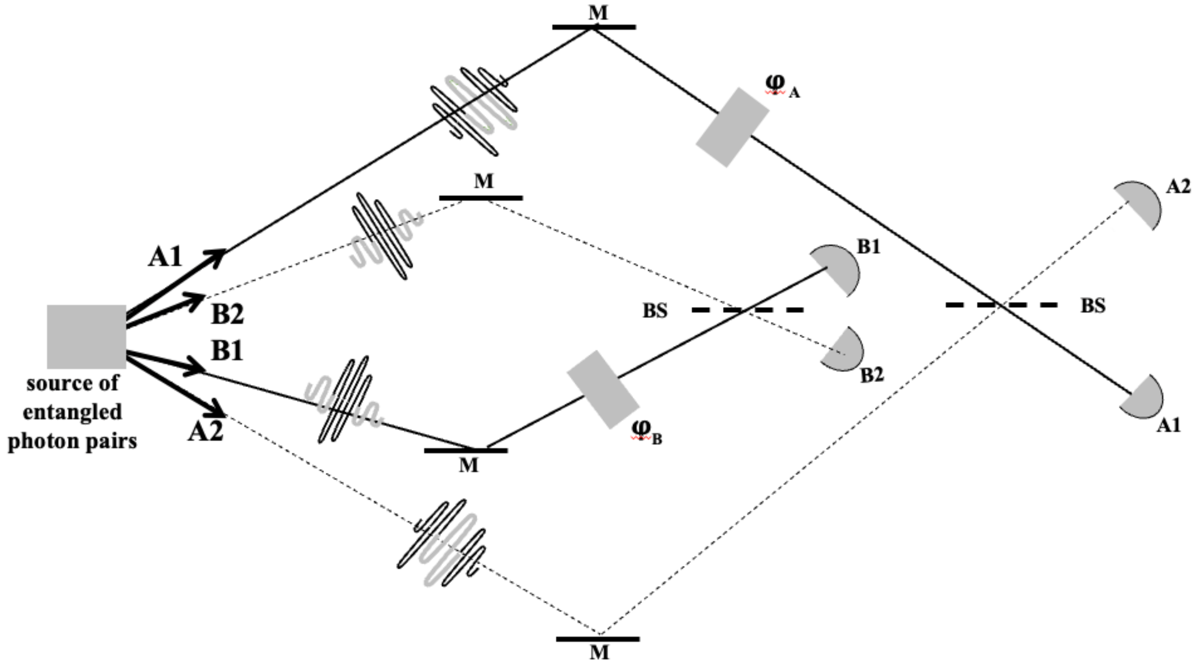

Figure 2. Layout of the RTO experiments. One photon emerges from the source along paths A1 and A2 while the other photon emerges along paths B1 and B2. The two photons form a single entangled "biphoton."

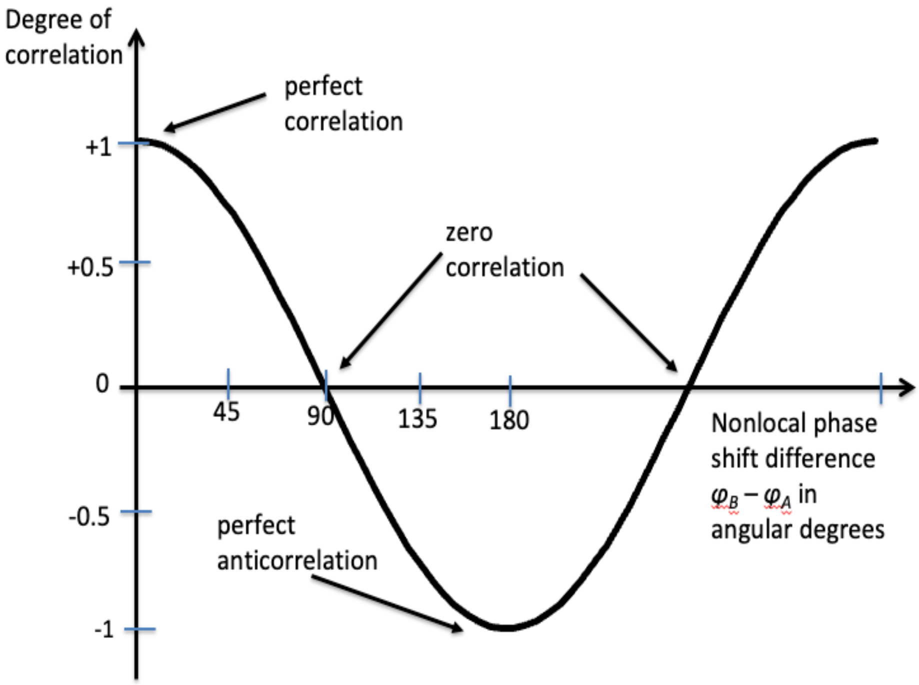

Figure 3. Nonlocal interference of RTO's bi-photon: Remarkably, the *degree of correlation* between RTO's two entangled photons varied sinusoidally with the nonlocal phase difference f_B-f_A.

Independently of violations of Bell's inequality, Fig. 3 provides straightforward evidence of nonlocality: Assume the phase shifters satisfy fA=fB, (note that pre-collaboration between the two detection stations would be required to establish this). According to Fig. 3, the two outcomes are then 100% correlated so that either observer can instantly read off the other observer's outcome simply by glancing at her own detector. Yet the two stations could be in separate galaxies (see the alternative set-up, Fig. 4)!

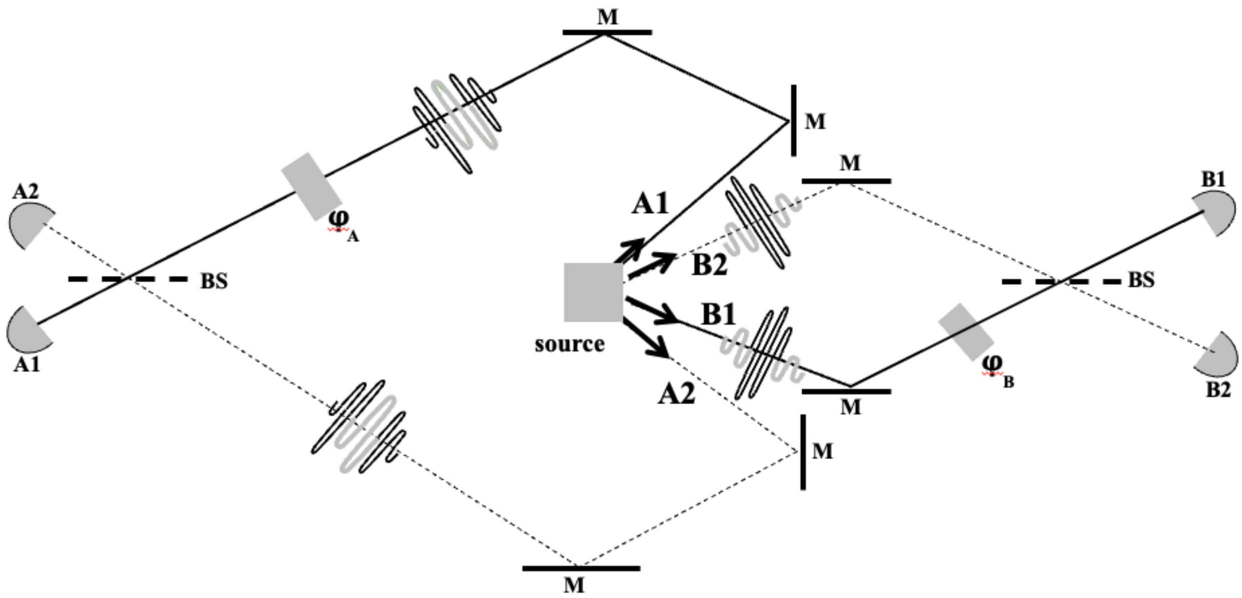

Figure 4. The RTO experiments, designed for widely separated detectors. (Compare Fig. 2)

Solution of the Problem of Outcomes

The RTO experiments found that, when two quantum objects A and B are entangled, the correlations between them become nonlocal: Regardless of their separation distance, alterations of the nonlocal phase difference fA-fB resulted in instantaneous alterations of their correlations. If we now return to the premeasurement state (4), we see that the problem of outcomes is solved: Simply allow subsystem B in (6) to be a macroscopic detector such as a Geiger counter or a cat. This creates no monstrous macroscopic superposition because B is incoherent and does not go through phases. Only the correlation between A and B goes through phases, as described above. If, for example, B is Schrodinger's cat, the cat is not coherent or "smeared" (as Schrodinger put it).

Conclusion: The entangled premeasurement state (4) is not an absurd macroscopic superposition. Neither subsystem is "smeared" (coherently phase-dependent). Only the correlations between the subsystems are coherent, and this is just what we want. The controversial premeasurement state of a quantum object and its detector is not an absurd superposition of detector states; it is instead a perfectly plausible superposition of correlations between detector states and quantum states of the object. This resolves the problem of outcomes.

Let's summarize the above analysis using the two-slit experiment as an example. The physical meaning of entanglement has been misunderstood. Consider the entangled premeasurement state (4) which we reproduce here:

$$\frac{|A1\rangle|D1\rangle + |A2\rangle|D2\rangle}{\sqrt{2}} \qquad (9)$$

where subsystem *A* is a single electron passing through a 2-slit experiment, and subsystem *D* is a pair of which-slit detectors. The |*Ai*> and |*Di*> *(i=1 or 2)* are, respectively, the states of the electron at the two slits and the states of the two detectors.

The following interpretation of (9) is **INCORRECT**:

A and *D* are respectively in states |*A1*> and |*D1*>
AND *A* and *D* are respectively in states |*A2*> and |*D2*> (10)

where "AND" indicates superposition. According to (10), the single electron is detected at both slits. This "superposition of paired states" is absurd and paradoxical.

Instead, the entangled state (9) represents a perfect *correlation between* states of *A* and states of *D*. That is,

A is in state |*A1*> **IF AND ONLY IF** *D* is in state |*D1*>
AND *A* is in state |*A2*> **IF AND ONLY IF** *D* is in state |*D2*> (11)

where "AND" again represents superposition. This "superposition of correlations" is what we want.

As another way of summarizing the present paper's key idea, let's compare Equations (2) and (4). (2) represents a coherent (i.e. phase-dependent) superposition *of states* of *A*. The problem of outcomes arises from viewing the entangled state (4) as a coherent superposition of the compound system *AB*. Instead, (4) represents a coherent (i.e. phase-dependent) and non-local superposition of *correlations between A* and *B*.

Solution of the Problem of Wave Function Collapse

Returning to Einstein's thought experiment, Fig. 1: The screen is an array of many small detectors such as photographic grains. As a single electron approaches the screen, we can describe its quantum state as an N-fold superposition over these detectors

$$|y> = \int |\mathbf{r}> y(\mathbf{r})\, d\mathbf{r} = C_N\, S_j \int_j |\mathbf{r}> y(\mathbf{r})\, d\mathbf{r} \quad (12)$$

where $\int$ represents an integral over the two-dimensional screen, |**r**> represents the electron's position eigenstate, y(**r**) = <**r**|y> is the electron's wave function, C_N is a suitable normalization constant, S_j is a sum over all detection regions, and $\int_j$ represents an integral over the jth detection region. (HOBSON, 2013). Equation (12) is analogous to the superposition (2) above. This state of the electron then entangles with the screen in a process analogous to Equation (3). The resulting entangled state is analogous to Equation (4):

$$|Y> = C_N\, S_j\, |j> \int_j |\mathbf{r}> y(\mathbf{r})\, d\mathbf{r} \quad (13)$$

where |j> represents the state of the jth detection region. As in Section 4, the measurement process therefore results in an entangled state that is analogous to the premeasurement state (4). Specifically, at the instant of detection, there is a perfect nonlocal correlation between the electron being in detection region j and the detector registering detection region j, for all j. The argument of Section 5 (above) then applies to this entangled premeasurement state.

This resolves the problem of wave function collapse.

Disproof of a Proposed Resolution of the Measurement Problem

One attempt to resolve the detection problem appears in Kurt Gottfried's popular graduate-level textbook (GOTTFRIED, 1966, 1991; GOTTFRIED *et al.*, 1991). The analysis employs the density operator formulation of quantum physics (SCHLOSSHAUER, 2007) It begins by forming the density operator for the entangled state (4),

$$r = |Y_{AD}> <Y_{AD}| = r_{diag} + r_{off\text{-}diag} \quad (14)$$

where the "diagonal" and "off-diagonal" parts of the density operator are defined by

$$r_{diag} = \{|A1>|D1> <D1|<A1|+|A2>|D2> <D2|<A2|\} / 2 \quad (15)$$

$$r_{off\text{-}diag} = \{|A1>|D1> <D2 <A2+|A2>|D2> <D1|<A1|\} / 2. \quad (16)$$

r_{diag} can be interpreted as an "ignorance mixture" in which the composite system is *either* in the state $|A1>\ |D1>$ *or* in the state $|A2>\ |D2>$ but nobody knows which. Thus, r_{diag} rather than *r* is often (but incorrectly, as we shall soon see) regarded as the desired solution to the detection problem. Replacing *r* with r_{diag} is thus a goal for Gottfried and seven other prospective solvers of the measurement problem (WIGNER, 1963; D'ESPAGNAT, 1966; FINE, 1970; SHIMONY, 1974; BROWN, 1986; BUSCH and SHIMONY, 1996; BACCIAGALUPPI, 2013).

Gottfried and Yan argue that $r_{off\text{-}diag}$ can, for all practical purposes, be neglected. This is because the expected value of any observable ***O*** is

$$<\boldsymbol{O}> = \mathrm{Tr}(r\, \boldsymbol{O}) = S_j\, S_k\, r_{jk}\, O_{kj} \quad (17)$$

where the off-diagonal terms (having $j \neq k$) contain matrix elements such as $O_{12} = <D1|\ <A1|\boldsymbol{O}|A2>\ |D2>$. Gottfried and Yan argue that such matrix elements are nonzero only for a "fantastic" observable ***O*** because $|D1>$ and $|D2>$ represent radically distinct detector states such as "dead cat" and "alive cat," or because the detectors *D1* and *D2* are separated by macroscopic distances. Thus, Gottfried and Yan assume that such non-diagonal matrix elements must be undetectably small and can, for all practical purposes, be neglected. This would imply that the "butchered" (John Bell's term) density operator r_{diag} can, for all practical purposes, replace *r*. [10]

However, this attempted resolution was doomed from the start. This is because the ignorance mixture (15) *cannot* be the desired premeasurement state because *it is not entangled and thus has no nonlocal characteristics*, while Einstein's thought experiment shows that non-local characteristics are *required*. The full density operator (14) *does* however have non-local characteristics. Thus $r_{off\text{-}diag}$ must incorporate the nonlocal aspects of detection *and cannot be neglected*.

Disproof of Seven "Proofs" of the Insolvability of the Measurement Problem

At least seven other "detection problem Insolvability proofs" make a similar mistake (WIGNER, 1963; D'ESPAGNAT, 1966; FINE, 1970; SHIMONY, 1974; BROWN, 1986; BUSCH and SHIMONY, 1996; BACCIAGALUPPI, 2013). These analyses differ, however, from Gottfried and Yan's analysis. These seven analyses assume that the ignorance mixture r_{diag} is the desired outcome of the measurement process. The initial state of *A* for all these analyses is assumed to be a pure state superposition (not a mixture) such as (2). The analyses then investigate whether a suitable post-measurement mixed state of the composite system can be reached via some unitary process. To achieve this, the detector must be represented initially by a mixed state because a unitary process cannot transform a pure state into a mixed state. All seven analyses regarded such an initial mixed state of the detector as appropriate because the detector is a macroscopic object.

Thus, the mathematical problem of all seven analyses was as follows: Find (i) an initial mixed-state density operator r_{ready} representing the detector *D* and find (ii) a unitary process *U,* such that *U* transforms the initial composite density operator $|Y_A\rangle\langle Y_A|\, r_{\text{ready}}$, with $|Y_A\rangle$ defined by (2), into the desired final state. This desired final state was a composite mixed state analogous to r_{diag}.

Each of the seven insolubility proofs showed, in different ways using different assumptions, that this mathematical problem has no solution: There is no initial mixed state r_{ready} and unitary process *U* that transforms $|Y_A\rangle\langle Y_A|\, r_{\text{ready}}$ into the desired final state. This presumably demonstrated the detection problem to be insolvable.

But again, this approach was doomed from the start because a composite mixed state analogous to r_{diag} has no nonlocal characteristics, so Einstein's analysis in 1927 tells us that it *cannot* correctly represent the desired solution of the detection problem.

Summary: Previous attempts to solve the detection problem, and previous supposed insolvability proofs, failed because they were looking in the wrong place. They assumed that the desired premeasurement state should be a mixture of non-entangled local states, while Einstein's remark shows that *the premeasurement state must be an entangled state* because it must have non-local characteristics.

CONCLUSIONS

This paper resolves the problem of definite outcomes that arise during the detection (or "measurement") process when a superposed quantum system interacts with a macroscopic detector to establish the entangled "premeasurement state" or "Schrodinger's cat state." The problem is that this state appears to be an absurd macroscopic superposition of every possible outcome. Experimental evidence arising from experiments with entangled photons demonstrates, however, that this state is not a coherent superposition of possible outcomes but rather a coherent superposition of all possible *correlations between* the possible outcomes and the corresponding states of the detector. This is precisely what we expect in a quantum measurement process. In the case of Schrodinger's cat, this premeasurement state reads as follows: "The cat is dead if and only if the nucleus decayed, AND the cat is alive if and only if the nucleus did not decay", where "AND" indicates a coherent (phase-dependent) superposition of correlations. This is what we want.

This resolves the problem of definite outcomes. It also resolves the related problem of wave function collapse that arises from the instantaneous nature of the transition from the premeasurement state to a single outcome – a transition that appears to violate special relativity. The resolution lies in the entangled, and hence non-local, nature of the premeasurement state.

We have also shown that one previously published presumed resolution of the measurement problem (GOTTFRIED, 1966, 1991; GOTTFRIED *et al.*, 1991) has a fatal flaw. That analysis suggests that the entangled premeasurement state can, for all practical purposes, be replaced by a non-entangled ignorance mixture. But such a mixture cannot represent the actual premeasurement state because it is not entangled and thus lacks non-local characteristics. Similarly, we disprove seven previously published presumed proofs of the insolvability of the measurement problem because they assume the desired premeasurement state is an ignorance mixture that lacks non-local characteristics, and this assumption is incorrect.

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