# A Summary of the Quantum Measurement Discussion

## A Suggested Resolution of the Problem of Definite Outcomes

### 1. Introduction

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

Since entangled states play a central role in most formulations of the measurement problem, and since entanglement is associated with nonlocal action, we investigate connections between nonlocality and measurement.

We review two 1991 experimental investigations of entangled photons that are remarkable for being the only nonlocality tests based on mechanical variables (namely photon momenta) rather than quantum variables such as polarization.

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 pre-measurement entangled state seems to describe a macroscopic measurement device that simultaneously yields all possible measurement outcomes even if they include "dead cat" and "alive cat."

Such a macroscopic superposition is absurd.

Section 3 reviews another common formulation of the measurement problem, first described by Einstein at the 1927 Solvay Conference.

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 compact region.

As Einstein noted, this appears to violate special relativity.

Section 4 presents an experimental context for properly understanding the measurement problem.

We examine two quantum optics experiments that demonstrate nonlocal action between two momentum-entangled photons .

Section 5 utilizes this understanding of nonlocal action to suggest a resolution of the problem of outcomes.

Similarly, Section 6 suggests a resolution of the puzzle of wave function collapse.

Section 7 shows that a well-known presumed resolution of the measurement problem has a fatal flaw.

Section 8 disproves seven presumed proofs of the measurement problem's insolvability.

Section 9 summarizes the conclusions.

## 2. The Problem of Outcomes ("Schrodinger's Cat")

First posed by E. Schrodinger and known as "Schrodinger's Cat", this formulation of the measurement problem is also known as the "problem of outcomes".

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: $|D_{ready}>$ 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" $D_1$ and $D_2$ present, respectively, at slits 1 and 2.

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) of **O**.

A minimally disturbing measurement is then represented by

$$|Ai\rangle \, |D_{ready}\rangle \Rightarrow |Ai\rangle \, |Di\rangle \qquad \text{(i = 1, 2)} \tag{1}$$

where the arrow represents the measurement process and the right-hand side represents the post-measurement state of the electron and its detector.

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 the eigenstates of **O**:

$$|\Psi_A\rangle = \frac{|A1\rangle + |A2\rangle}{\sqrt{2}} \tag{2}$$

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

$$\frac{(|A1\rangle + |A2\rangle)}{\sqrt{2}} |D_{ready}\rangle \Rightarrow |\Psi_{AD}\rangle \tag{3}$$

where $|\Psi_{AD}>$ is defined as

$$|\Psi_{AD}\rangle = \frac{|A1\rangle |D1\rangle + |A2\rangle |D2\rangle}{\sqrt{2}} \tag{4}$$

A similar enigmatic entangled state crops up in nearly every analysis of the measurement problem. We will call it the "premeasurement state."

As one expert aptly put it, “The problem of what to make of this” (namely (4)) “is called the measurement problem“.

It is known from experiment that the outcome after such a "measurement" ("detection" would be a more accurate word) is random.

More specifically,

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

The theoretically predicted consequence of measurement (4) is said to "collapse" to a single randomly chosen outcome as described further in Section 3 below.

Equation (4) does not appear to be equivalent to (5).

This apparent contradiction is known as the "problem of outcomes."

Since a dyad such as |A1>|D1> is usually interpreted as a state of the composite system AD in which subsystem A is described by state |A1> and subsystem D is described by state |D1>, equation (4) seems to represent an absurd macroscopic 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 passing through both slits, causing both detectors to click.

According to (5), this is not what is observed.

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 .

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” (phase dependence, or “coherence”).

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 ψ 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 $|Ai\rangle\, |Di\rangle$ ($i = 1, 2$).

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?

Before 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.

## 3. 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 Figure 1)

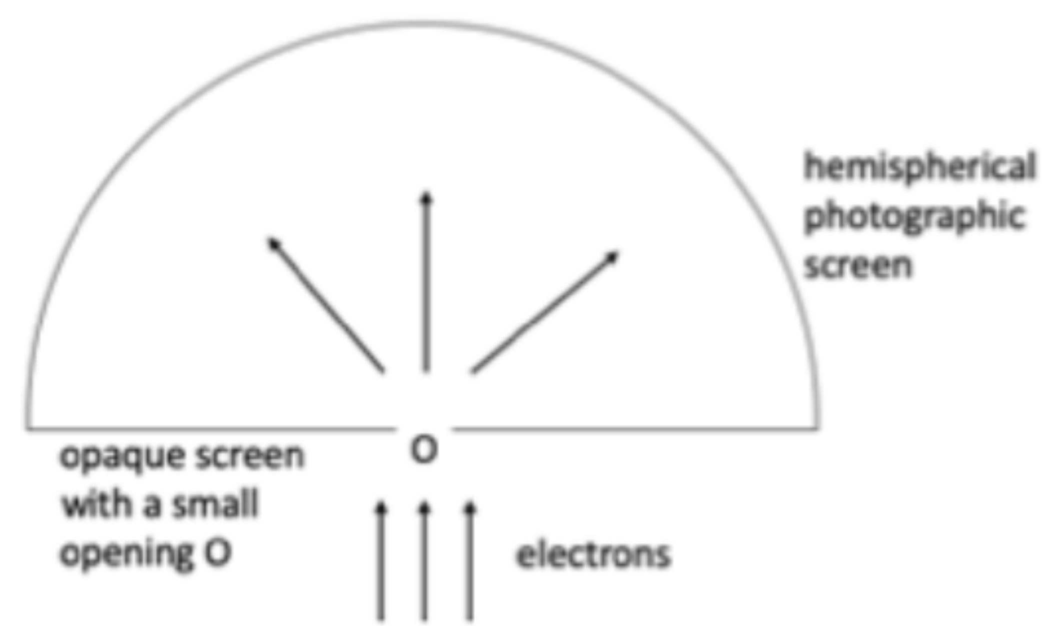


**Figure 1:** Einstein's thought experiment. On each trial, a single electron diffracts widely and then simultaneously arrives at every point on the hemispherical screen. Yet only one point registers an impact! How do the other points instantaneously remain dark? This appears to violate special relativity.

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.

## 4. Experiments with momentum-entangled photons

Two quantum optics experiments 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 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.

Within a nonlinear bi-refringent crystal, RTO transformed a single high-frequency photon into two entangled lower-frequency photons.

By carefully selecting these “biphoton” pairs in each trial, RTO were able to create multiple copies of a specific pair.

Figure 2 shows the subsequent trajectories of one biphoton .

The figure doesn’t show the full 3-dimensional view, which is as follows:

The biphoton emerges along the intersection of two cones whose center lines are separated by 28.6 degrees.

We shall represent this entangled state by

$$|\Psi_{AB}\rangle = \frac{|A1\rangle\,|B1\rangle + |A2\rangle\,|B2\rangle}{\sqrt{2}} \tag{6}$$

where |Ai> represents two states of the first photon and |Bi> represents two states of the second photon (i = 1, 2).

Equation (6) is isomorphic to (4) with the important distinction that, in (6), both subsystems are microscopic.

As we shall see, this state exhibits nonlocality.

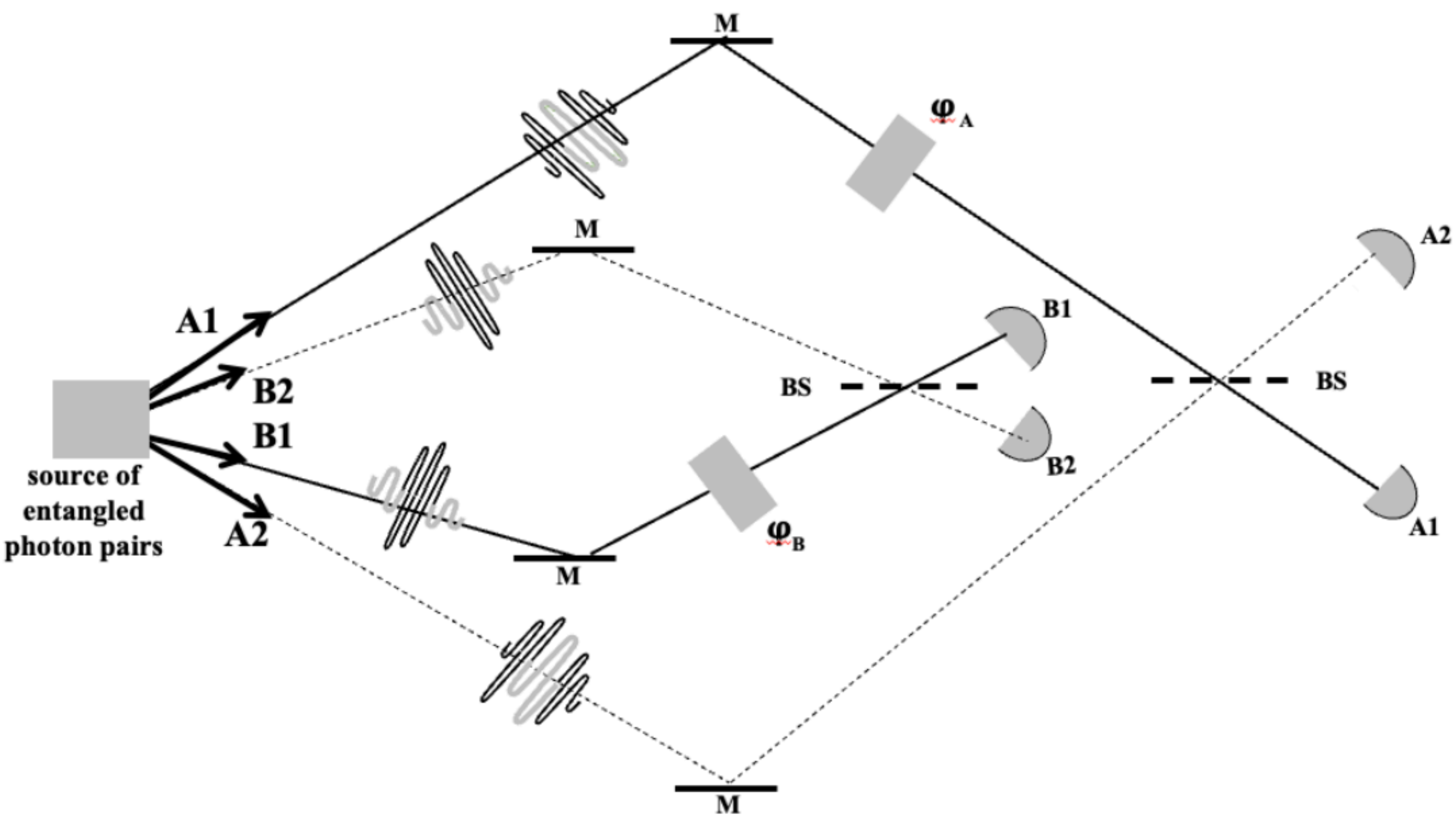


**Figure 2.** Layout of the RTO experiments. One photon emerged from the source along paths A1 and A2 while the other photon emerged along paths B1 and B2. The two photons formed a single entangled "biphoton"

2022 Physics Nobel laureate Alain Aspect remarked 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.

Quoting a 2022 interview with Aspect:

**Interviewer:** “We know and you can confirm that you would like to see a Bell test made with material particles rather than photons.

Can you elaborate on your motivation for such a test …knowing that it is clearly a difficult and challenging experiment?”

**Aspect:** ”My idea is the following: All tests of Bell’s inequality up to now (well, almost all…) have been done with two-level systems, photon polarization, two levels in an ion, etc.

I think that doing it with momentum, which is a mechanical degree of freedom, would be interesting.

Well, there is one experiment that has been done with momentum.

Here, Aspect references the paper by Rarity and Tapster.

But it’s with photons.

You can reproduce pairs of entangled photons that are superpositions of |+p, -p> and |+p’, -p’>.

So it is with momentum, but it uses photons.

I want an experiment of that kind, with mechanical degrees of freedom, momentum, done with massive particles.

And the reason is that we know that there is a tension between quantum mechanics and, let’s say, gravity.

So at some point, why not try to do an experiment like that?

The group at Institut d’Optique has embarked into such an experiment.

I doubt that with a light atom like helium you will find something, but one has to start and see.”

Returning to Figure 2, biphoton pairs were in the entangled state (6) as they emerged from the source.

Photon A followed two paths A1 and A2, while B followed two other paths B1 and B2.

Variable phase shifters $\phi_A$ and $\phi_B$ were inserted into one of A's two paths and one of B's two paths, respectively.

We label these phase shifts $\phi_A$ and $\phi_B$.

The results: Remarkably, neither photon interfered with itself as a function of its own phase $\phi_A$ or $\phi_B$.

That is, individual photons were incoherent rather than phase-dependent or "smeared.”

In particular, the results at the four detectors were

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

regardless of the phase settings $\phi_A$ and $\phi_B$.

This incoherence must be attributed to the entanglement.

But the system's 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 $\phi_A$-$\phi_B$ 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 Figure 3.

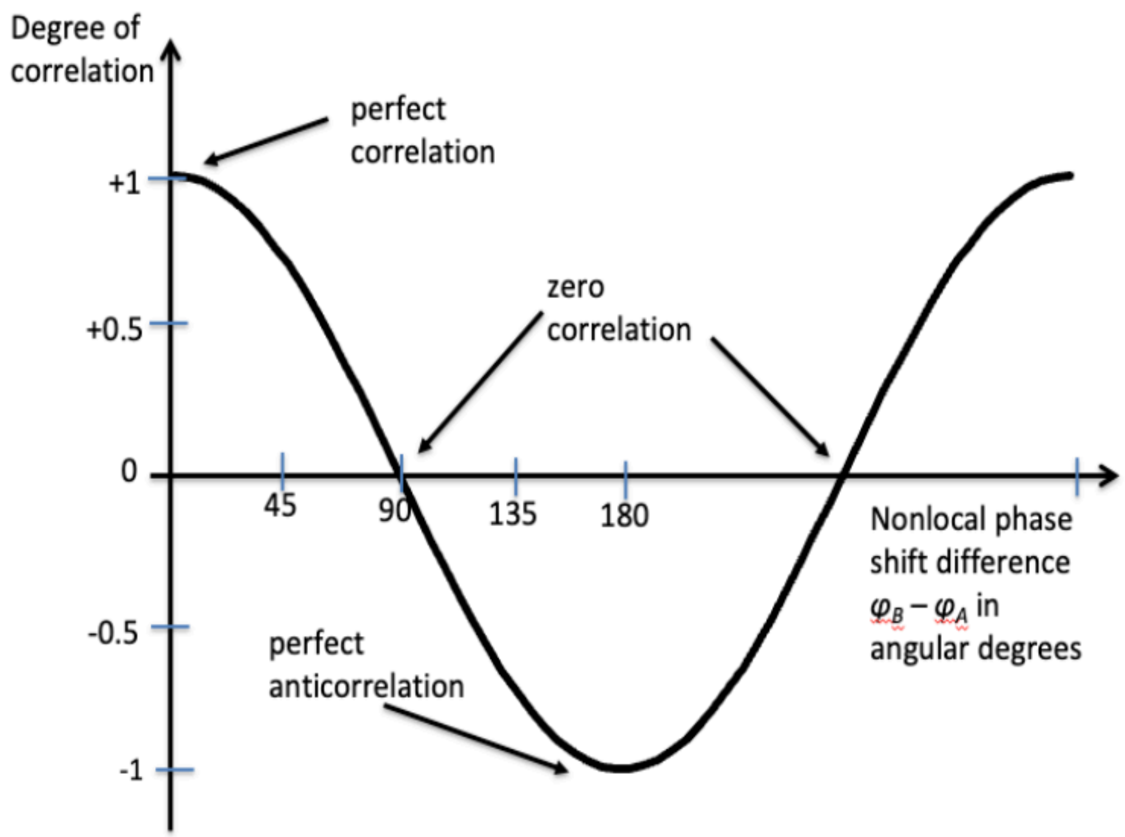


**Figure 3.** Nonlocal interference of RTO's bi-photon: Remarkably, the degree of correlation between RTO's two entangled photons varied sinusoidally with the nonlocal phase difference $\phi_B$-$\phi_A$ .

Figure 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 "decohere" 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."

Independently of violations of Bell's inequality, Figure 3 provides the following straightforward evidence of nonlocality: Assume the phase shifters satisfy $\phi_A = \phi_B$ (note that pre-collaboration between the two detection stations would be required to establish this).

According to Figure 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 on separate galaxies (see the alternative long-distance set-up, Figure 4)!

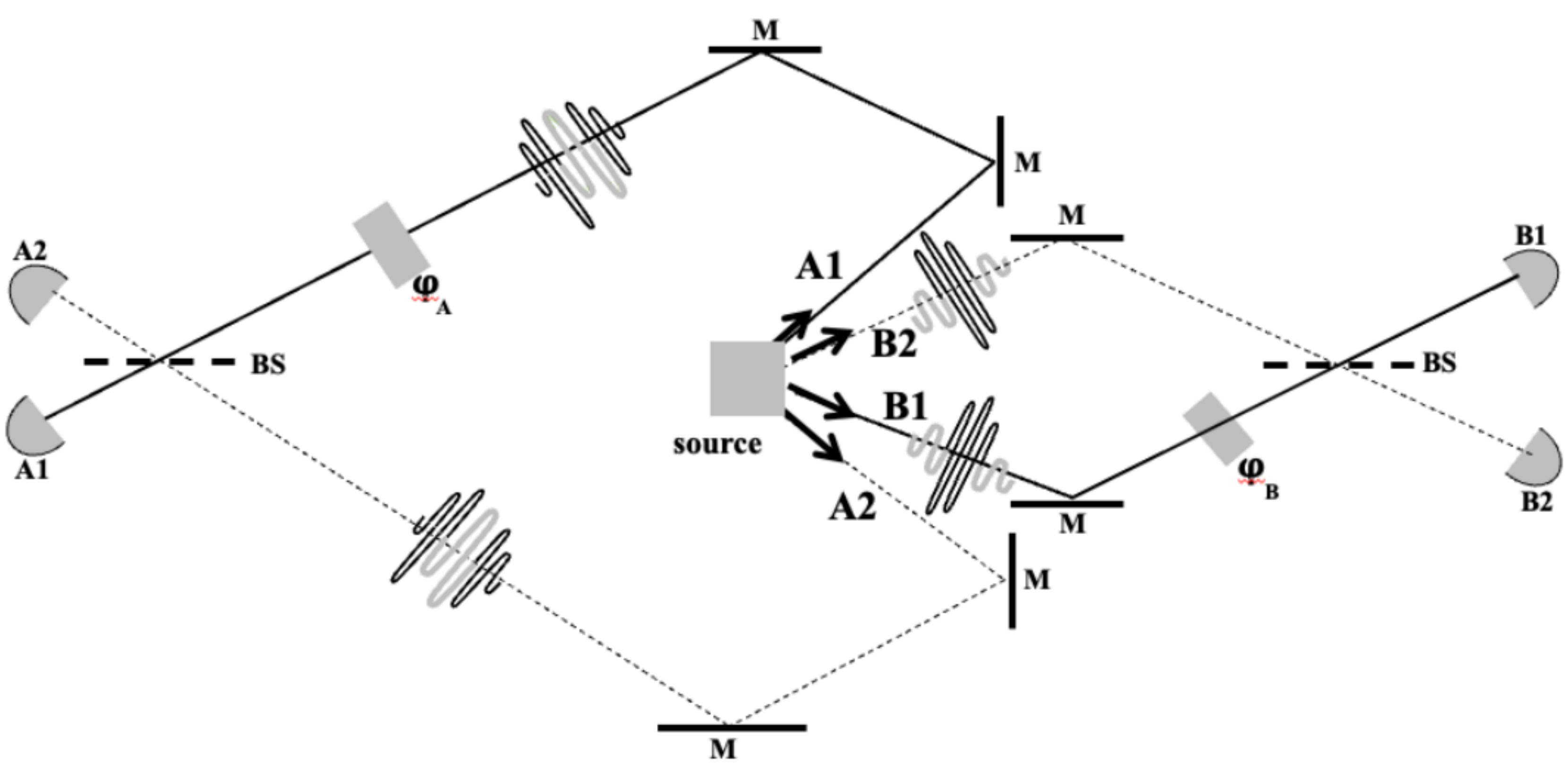


**Figure 4.** The RTO experiments, designed for widely separated detectors. Compare Figure 2.

## 5. Solution of the Problem of Outcomes

Summarizing Section 4: 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 $\phi_A - \phi_B$ 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

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

where subsystem A is a single electron passing through a 2-slit experiment, and subsystem D is a pair of which-slit detectors.  |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.

Such a 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 this 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 definite 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.

The distinction between interpretation (10) and interpretation (11) is not just semantic.

Interpretation (10) says that the entangled state (4) entails that all four states |Ai> and |Bi> (i = 1, 2) exist, which implies that Schrodinger's cat is simultaneously dead and alive.

Interpretation (11) says that the entangled state (4) entails that either |A1> and |D1> exist or |A2> and |D2> exist, which is not absurd.

## 6. Solution of the Problem of Wave Function Collapse

Let's return to Einstein's thought experiment, Figure 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

$$|\psi\rangle = \int |r\rangle\, \psi(r)\, dr = C_N \Sigma_j \int_j |r\rangle\, \psi(r)\, dr \qquad (12)$$

where $\int$ represents an integral over the two-dimensional screen, $|\mathbf{r}\rangle$ represents the electron's position eigenstate, $\psi(\mathbf{r}) = \langle \mathbf{r}|\psi\rangle$ is the electron's wave function, $C_N$ is a suitable normalization constant, $\Sigma_j$ is a sum over all detection regions, and $\int_j$ represents an integral over the jth detection region.

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):

$$|\Psi\rangle = C_N \Sigma_j |j\rangle \int_j |r\rangle\, \psi(r)\, dr \qquad (12)$$

where $|j\rangle$ 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.

## 7. Disproof of a Proposed Resolution of the Measurement Problem

One attempt to resolve the detection problem appears in Kurt Gottfried's well-known graduate-level textbook.

Gottfried's analysis employs the density operator formulation of quantum physics.

It begins by forming the density operator for the entangled state (4),

$$\varrho = |\Psi_{AD}\rangle \langle\Psi_{AD}| = \varrho_{diag} + \varrho_{off\text{-}diag} \tag{14}$$

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

$$\varrho_{diag} = \{|A1\rangle|D1\rangle \langle D1|\langle A1|+|A2\rangle|D2\rangle \langle D2|\langle A2|\} / 2 \tag{15}$$

$$\varrho_{off\text{-}diag} = \{|A1\rangle|D1\rangle \langle D2 \langle A2+|A2\rangle|D2\rangle \langle D1|\langle A1|\} / 2. \tag{16}$$

$\varrho_{diag}$ can be interpreted as an "ignorance mixture" in which the composite system is either in the state $|A1\rangle\ |D1\rangle$ or in the state $|A2\rangle\ |D2\rangle$ but nobody knows which.

Thus, $\varrho_{diag}$ rather than $\varrho$ is often (but incorrectly, as we shall soon see) regarded as the desired solution to the detection problem.

Replacing $\varrho$ with $\varrho_{diag}$ is thus a goal for Gottfried and seven other prospective solvers of the measurement problem.

Gottfried and Yan argue that $\varrho_{off\text{-}diag}$ can, for all practical purposes, be neglected.

This is because the expected value of any observable **O** is

$$\langle \mathbf{O} \rangle = \mathrm{Tr}(\varrho\, \mathbf{O}) = \Sigma_j \Sigma_k \varrho_{jk} O_{kj} \tag{17}$$

where the off-diagonal terms (having $j \neq k$) contain matrix elements such as $O_{12} = \langle D1| \langle A1|\mathbf{O}|A2\rangle |D2\rangle$.

Gottfried and Yan argue that such matrix elements are nonzero only for a "fantastic" observable **O** because $|D1\rangle$ and $|D2\rangle$ 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 $\varrho_{diag}$ can, for all practical purposes, replace $\varrho$.

However, the ignorance mixture (15) cannot be the desired pre-measurement state because it is not entangled and thus has no nonlocal characteristics, while Einstein's thought experiment shows that nonlocal characteristics are required.

The full density operator (14) does however have nonlocal characteristics.

Thus $\varrho_{\text{off-diag}}$ must incorporate the nonlocal aspects of detection and cannot be neglected.

I hasten to add that this flaw occurs in an otherwise wonderful textbook.

Consider, for example, the words of the great John Bell who also disagreed with Gottfried's measurement problem analysis while describing the text as "indeed a good book" and giving three reasons:

"(i) The CERN library had four copies. Two have been stolen—already a good sign. The two that remain are failing apart from much use.

(ii) It has a good pedigree. Kurt Gottfried was inspired by the treatments of Dirac and Pauli. His personal teachers were J. D. Jackson, J. Schwinger, V. F. Weisskopf and J. Goldstone. As consultants he had P. Martin, C. Schwartz, W. Furry, and D. Yennie.

(iii) I have read some of it more than once."

## 8. Disproof of Seven "Proofs" of the Insolvability of the Measurement Problem

At least seven other "measurement problem Insolvability proofs" make a similar mistake.

These analyses differ, however, from Gottfried and Yan's analysis.

These seven analyses assume that the ignorance mixture $\varrho_{diag}$ 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 (before the measurement) 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 $\varrho_{ready}$ representing the detector D and find (ii) a unitary process U, such that U transforms the initial composite density operator $|\Psi_A\rangle\langle\Psi_A|\ \varrho_{ready}$, with $|\Psi_A\rangle$ defined by (2), into the desired final state.

This desired final state was a composite mixed state analogous to $\varrho_{diag}$.

mathematical problem has no solution: There is no initial mixed state $\varrho_{ready}$ and unitary process U that transforms $|\Psi_A\rangle \langle\Psi_A| \varrho_{ready}$ 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 $\varrho_{diag}$ 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 of Section 8: 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 nonlocal characteristics.

## 9. Conclusions

This discussion resolves the problem of definite outcomes that arises 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 such as “dead cat” and “alive cat.”

Experiments with entangled photons demonstrate, however, that detection transfers coherence from individual objects (such as a cat) to the *correlations* between the object and its detector while rendering the object and its detector incoherent.

Thus Schrodinger's cat is incoherent and the entangled premeasurement state is not a coherent superposition of all possible outcomes but rather a coherent superposition of all possible *correlations* between possible outcomes and the corresponding states of the detector:

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 instantaneous 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 nonlocal, nature of the premeasurement state.

We have also shown that one previously published presumed resolution of the measurement problem is flawed.

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.