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Posted Date: 11 March 2025

doi: 10.20944/preprints202503.0798.v1

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Article

Completing Quantum Mechanics Within the Framework of Local Realism

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Abstract: As we all know, Einstein disagreed with Born's probabilistic interpretation of wave-functions, which collapse abruptly once measurements are performed on the corresponding systems. In the Einstein-Bohr debate, Einstein considered quantum mechanics incomplete. Inspired by Einstein, Bell and his followers intended to complete quantum mechanics within the framework of local realism. Regrettably, *deterministic correlations* in Einstein's local-realist description of the world are mistaken for "nonlocal-interactions" (non-locality) in the world described by Bell's theorem, which leads to the questionable interpretation of the experimental results obtained by testing Bell inequalities. This article introduces a new principle, *the general principle of measurements*, which is proved as a mathematical theorem and allows quantum mechanics to be completed within the framework of local realism while keeping the axiomatic definition of a *general* Hilbert space essentially unchanged. Using disjunction ("or") as the logical relation between orthonormal vectors spanning a given Hilbert space, the completed quantum theory precludes inexplicable collapses of wave-functions and is intuitively comprehensible, thus alleviating much difficulty in understanding quantum mechanics. Among various world views, Einstein's local-realist world view is correct.

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1. Introduction

In Einstein's local-realist description of the world, values of physical quantities exist objectively, and measurements performed on a system cannot immediately affect another distant system, as shown in the Einstein-Bohr debate [1,2]. The essence of the debate is the legitimacy of quantum superpositions. Einstein disagreed with Born's probabilistic interpretation of wave-functions, which are expressed by quantum superpositions. Born's probabilistic interpretation cannot account for randomness in quantum physics. Once a measurement is performed on a system, the corresponding wave-function collapses abruptly. Because the quantum-mechanical description of the world "cannot be reconciled with the idea that physics should represent a reality in time and space, free from spooky actions at a distance" ([3], p.158), Einstein called it "the fundamental dice-game" ([3], p.149).

Based on local realism, Einstein, Podolsky, and Rosen (EPR) questioned the completeness of quantum mechanics by revealing a contradiction in its conceptual foundations: the truth of Heisenberg's uncertainty relation implies the incompleteness of quantum mechanics; by contra-position, the completeness of quantum mechanics implies the falsity of Heisenberg's uncertainty relation [1]. Their argument rests on the existence of *correlations* between *distant* components of the combined system ([4], p.225). Bohr defended quantum mechanics without mentioning the correlations [2]. Thus the contradiction EPR revealed cannot be explained away.

Inspired by Einstein, Bell and his followers intended to complete quantum mechanics within the framework of local realism [5]. Bell derived the first of Bell inequalities to be tested by experiments [6–9] and proved Bell's theorem to interpret the experimental results [6]. To his surprise, his theorem shows Einstein to be wrong in the Einstein-Bohr debate [6,10], which is the opposite of what Bell intended [5,11]. Why does Bell's approach lead him to prove the opposite of what he intended? Can quantum

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mechanics be completed in a way different from Bell's approach? If yes, does the completed quantum theory imply the falsity of Heisenberg's uncertainty relation? Concerning different understandings of Bell's theorem [12–17], including those disproving or questioning Bell's theorem [16,17], the questions are still open. This study aims to answer the above questions by introducing a new principle, *the general principle of measurements*, which is proved as a mathematical theorem. The main findings are as follows. Bell's approach is problematic; *deterministic correlations* in Einstein's local-realist description of the world are mistaken for "nonlocal-interactions" (non-locality) in the world described by Bell's theorem. Quantum mechanics can be completed within the framework of local realism in a way consistent with the axiomatic definition of a *general* Hilbert space. Using disjunction ("or") as the logical relation between superposed orthonormal vectors, the completed quantum theory precludes inexplicable collapses of wave-functions and is intuitively comprehensible, thus alleviating much difficulty in understanding quantum mechanics. Among various world views, Einstein's local-realist world view is correct.

2. Bell's Approach Revisited

When deriving Bell inequalities [6–9] by resorting to a hidden-variable theory [18–20], Bell and his followers merely tried to reinterpret quantum mechanics while keeping the theory in its current form intact [11]. Thus Bell's approach presumes the legitimacy of the current quantum theory. Purportedly obtained from the hypotheses underlying the EPR argument, Bell inequalities cannot capture the essence of the Einstein-Bohr debate, namely, the legitimacy of quantum superpositions. Einstein never endorsed any hidden-variable theory ([4], p.254). Nevertheless, Bell regarded Einstein as a proponent of hidden variables [6] and maintained his views (see Ref. /23/ in [21] and [22]). Influenced by Bell, some physicists believe that there exists a linkage between hidden variables and elements of physical reality [9,10]. Such a linkage is nonexistent.

Bell inequalities are not results about quantum mechanics. But the world described by Bell's theorem is the world described by quantum mechanics, which differs substantially from Einstein's local-realist world view. In Einstein's local-realist description of the world, the *correlations* between *distant* components of the combined system are due to interactions occurred *before* the components spatially separated; *after* the separation, there are no longer any interaction between the *distant* components. But the *correlations* still exist, even though the components have spatially separated [1]. Regrettably, the *correlations* in Einstein's local-realist description of the world [1] are mistaken for "nonlocal-interactions" in the world described by Bell's theorem ([10], pp. 1886-1887), which leads to the questionable interpretation of the experimental results obtained by testing Bell inequalities. The questionable interpretation has led to serious consequences as shown below.

One of Bell inequalities, the CHSH inequality [7], has been intensively tested by actual experiments with *single* pairs of *correlated* photons using technologies of modern optics [8,9]. According to Bell's theorem, the Einstein-Bohr debate seems to have been resolved "in the way which Einstein would have liked least" [20]. Nowadays people believe that Einstein's local-realist world view conflicts with the experimental results of testing the CHSH inequality [9,10].

However, derived based on the nonexistent linkage between hidden variables and elements of physical reality, the CHSH inequality merely represents an unsuccessful attempt to reinterpret quantum mechanics by reproducing its statistical predictions while presuming the legitimacy of quantum superpositions. Thus the CHSH inequality cannot capture the essence of the Einstein-Bohr debate, and the hypotheses underlying the EPR argument are irrelevant to Bell's theorem. But why are the *correlations* in Einstein's local-realist description of the world mistaken for "nonlocal-interactions" in the world descried by Bell's theorem? Before answering this question, it is necessary to introduce a new principle, *the general principle of measurements*, which can be proved as a mathematical theorem.

3. General Principle of Measurements

Physical quantities are all measured in the real world based on mathematical models of space and time. Thus the corresponding models must be identified first before the new principle is introduced and proved mathematically. The mathematical model of space is the three-dimensional Euclidean space $\mathbb{R}^3$ endowed with the metric given by the usual distance function between two points in space; a point $z \in \mathbb{R}^3$ represents a precise space coordinate. The mathematical model of time is the set of nonnegative real numbers R_0 equipped with the metric given by the usual distance function between two nonnegative real numbers; an element $t \in R_0$ is a precise time coordinate.

To prove the general principle of measurements as a mathematical theorem, let us recall a few definitions about "metric space" and "point-set topology". A metric space is denoted by (X, d), where X is a set, and d is a metric on X. Let $r > 0$ be a real number. For $x \in X$, the open ball with center x and radius r is

$$B(x;r) = \{y \in X : d(x,y) < r\}. \tag{1}$$

Any open subset of X is a union of open balls. All open subsets of X constitute a metric topology $\mathcal{T}_X$ for X. The metric topology $\mathcal{T}_X$ and X form a metric topological space. Consider $x \in S$ where $S \in \mathcal{T}_X$. If there exists $r > 0$ such that

$$B(x;r) \cap S = \{x\}, \tag{2}$$

then x is an isolated point of S. Denote by $\mathcal{T}_{\mathbb{R}^3}$ and $\mathcal{T}_{R_0}$ the the metric topologies for $\mathbb{R}^3$ and R_0 associated with the metrics given by the corresponding distance functions, respectively. Apparently, measuring a point z in space perfectly precisely requires z to be an isolated point of $\mathbb{R}^3$. Similarly, unless time t is an isolated point of R_0, it is impossible to measure t perfectly precisely.

Theorem 1. *(The General Principle of Measurements): Precise space and time coordinates are practically unattainable by measurements, or equivalently, neither $\mathbb{R}^3$ nor R_0 has isolated points.*

Proof. Consider first an arbitrarily given $z \in S$, where $S \in \mathcal{T}_{\mathbb{R}^3}$ is arbitrary. Evidently, there is no $r > 0$ such that

$$B(z;r) \cap S = \{z\}. \tag{3}$$

Thus $\mathbb{R}^3$ has no isolated point. Now consider $t \in S$, where $S \in \mathcal{T}_{R_0}$ is arbitrary. An open "ball" now is an open interval

$$B(t;r) = (t - r, t + r). \tag{4}$$

There are two cases: $t = 0$, and $t > 0$. If $t = 0$, then $B(0;r) \notin \mathcal{T}_{R_0}$ for any $r > 0$, and there is no $S \in \mathcal{T}_{R_0}$ such that

$$S \cap B(0;r) = \{0\}. \tag{5}$$

Thus 0 is not an isolated point of R_0. If $t > 0$, there is no $r > 0$ such that

$$S \cap B(t;r) = \{t\}. \tag{6}$$

Thus t is not an isolated point of R_0 either. Consequently, R_0 has no isolated point. □

Proved as a mathematical theorem, the general principle of measurements does not involve issues concerning practical measurements raised by Bohr [2] or accuracy of measurement outcomes in practice. Any random phenomenon observed in physics can only be described reasonably after a large number of measurement outcomes are obtained in *different* repetitions of a given experiment under "the same experimental conditions" specified by precise space and time coordinates. According to the general principle of measurements, "the same experimental conditions" so specified do not exist in the real world.

Before the advent of quantum mechanics, physicist held a commonsense: the same experimental conditions always produce the same results. In other words, results produced by the same experimental conditions are deterministic. This commonsense is approximately true. Random phenomena observed in classical physics are mainly due to lack of knowledge needed to describe physical situations that typically involve a large number of single microscopic objects; their behaviors are usually assumed to be independent. Randomness in such situations is explainable using statistical mechanics. The general principle of measurements is ignorable. Quantum mechanics changed this commonsense.

Nowadays physicists hold a new commonsense: the same experimental conditions do not produce the same results in quantum physics, or equivalently, the results produced by the same experimental conditions in quantum physics are random [23]. However, this new commonsense is misleading and largely responsible for erroneously interpreted experimental results. Mutually exclusive properties are observed in *different* repetitions of an experiment, correspond to *different* measurement outcomes associated with *different* objects of the same kind, but are attached to an *imaginary* object. As a consequence of violating the general principle of measurements by taking precise space and time coordinates for granted to specify "the same experimental conditions", the *imaginary* object does not existent in the real world. Thus the origin of randomness in quantum physics is concealed. In various experiments involving quantum superpositions, randomness actually stems from violating the general principle of measurements by taking precise space and time coordinates for granted. Caused by lack of knowledge concerning precise space and time coordinates used to specify "the same experimental conditions", such randomness is not explainable using statistical mechanics.

Consider, again, the optical experiment designed to test the CHSH inequality [9]. Expressed as a quantum superposition, an "entangled state" describes the single pairs of correlated photons and is used to calculate the probabilities of obtaining the corresponding outcomes by measuring the polarizations of the correlated photons in the pairs, which implies the legitimacy of Born's probabilistic interpretation of wave-functions. Thus the failure of the CHSH inequality is inevitable. The "entangled state" depends on "the same experimental conditions" specified by precise space coordinates, which are the corresponding points on a unit sphere $U \subset \mathbb{R}^3$. "Bloch sphere" is not contained in $\mathbb{R}^3$ and should not be confused with U. The points on U correspond to (a) the polarizations as well as propagating directions of *different* photons detected in *different* repetitions of the experiment, and (b) the orientations of the polarizers for measuring the polarizations of the photons. Taking the precise space coordinates for granted [9], the "entangled state" violates the general principle of measurements and is illegitimate. The random phenomenon observed in the experiment is exactly due to lack of knowledge about the precise space coordinates used to specify "the *same* experimental conditions" for measuring the polarizations of *different* photons detected in *different* repetitions. Using statistical mechanics cannot explain such randomness. Randomness caused by lack of knowledge about precise time coordinates can be analyzed similarly.

4. Hilbert Space in Quantum Mechanics

In 1927, John von Neumann provided the first axiomatic definition of a *general* Hilbert space. Based on the axiomatically defined *general* Hilbert space, von Neumann also provided an axiomatic formulation of quantum mechanics as its formal foundation. The name of "Hilbert space" is in honor of David Hilbert. At the beginning of the last century, Hilbert studied the classical prototype of what is known today as a Hilbert space in his work on the theory of integral equations. In functional analysis, mathematicians now denote this space by ℓ^2. The general principle of measurements allows quantum mechanics to be completed within the framework of local realism in a way consistent with the axiomatic definition of a *general* Hilbert space.

Concepts used in the axiomatic definition of a *general* Hilbert space are all highly abstract notions and have no practical meanings. Specified by an inner product, orthogonality is a purely mathematical concept. Assigning practical meanings to orthogonality is unnecessary. Moreover, the logical relation between orthogonal vectors is not needed in the axiomatic definition of a *general* Hilbert space. Only in a given application, practically meaningful concepts are necessary to define a specific Hilbert space used to describe practically meaningful objects, and conjunction ("and") may serve as the logical relation between orthogonal vectors in that space. But orthogonal vectors must not correspond to mutually exclusive properties simultaneously belonging to the same object; such an imaginary object is a consequence of violating the general principle of measurements by taking precise space and time coordinates for granted to specify "the same experimental conditions". As shown in the last section, neither "the same experimental conditions" nor the imaginary object exist in the real world.

The *general* Hilbert space differs from any Hilbert space in quantum mechanics. The difference between the former and the latter is that the concept of orthogonality in the latter has a specific meaning: conjunction ("and") is the logical relation between orthonormal vectors, which purportedly represent mutually exclusive properties simultaneously belonging to the same physical object. Thus the Hilbert space in quantum mechanics is questionable, although von Neumann's axiomatically defined *general* Hilbert space is still valid.

Elements of ℓ^2 are infinite sequences of complex numbers. The logical relation between orthogonal vectors spanning ℓ^2 is neither conjunction ("and") nor disjunction ("or"). With the inner product defined for Euclidean vectors, $\mathbb{R}^3$ is a Hilbert space. Orthogonal vectors spanning $\mathbb{R}^3$ do not represent mutually exclusive properties simultaneously belonging to any geometric object, and the logical relation between the orthogonal vectors is conjunction ("and").

Disjunction ("or") can also serve as the logical relation between orthogonal vectors. For a Hilbert space in quantum mechanics completed based on the general principle of measurements, the logical relation is disjunction ("or"). *Different* outcomes corresponding to *mutually exclusive* properties represented by orthonormal vectors spanning a Hilbert space in quantum mechanics are associated with *different* physical objects of the *same* kind, which are measured in *different* repetitions of a given experiment. Obtained by measuring the corresponding object, each *single* outcome reveals an element of the physical reality. Consequently, a value corresponding to the *single* outcome can be assigned to the object, even though the precise space and time coordinates used to measure it are unknown; the value can even be taken from a continuum and cannot be obtained by measurements, such as the position or momentum of a particle moving in space.

Thus, based on the general principle of measurements, quantum mechanics can indeed be completed within the framework of local realism, such that the completed quantum theory is consistent with the axiomatic definition of a *general* Hilbert space without changing the mathematical setting substantially. In the definition of a *general* Hilbert space, the axioms concerning various calculations in quantum mechanics will all remain unchanged, which will simplify the axiomatic formulation of quantum mechanics: the questionable axioms, such as those implying the purported completeness of the current quantum theory, the inherently probabilistic nature of observations on quantum systems, and inexplicable collapses of wave-functions triggered by measurements, are irrelevant to the calculations and should be removed from the axiomatic formulation of quantum mechanics. Disjunction ("or"), the logical relation between superposed orthonormal vectors in the completed quantum theory, differs essentially from conjunction ("and"), the logical relation in the current quantum theory. To avoid confusion, the former and the latter will be denoted by "superposition (disjunction)" and "superposition (conjunction)", respectively. Violating the general principle of measurements will result in using an *imaginary* object described by superpositions (conjunction) to characterize *different* objects measured in *different* repetitions. No outcome is obtained by measuring the imaginary object, which is nonexistent in the real world.

The EPR argument reveals a contradiction in the conceptual foundations of quantum mechanics, namely, the truth of Heisenberg's uncertainty relation implies the incompleteness of the current quantum theory, or equivalently, the completeness of quantum mechanics in its current form implies the falsity of Heisenberg's uncertainty relation [1]. After quantum mechanics is completed within the framework of local realism, does the completed quantum theory imply the falsity of Heisenberg's uncertainty relation? The answer is yes. In the real world, there is no particle described by a wave-function expressed as a superposition (conjunction), which implies an inexplicable collapse of the wave-function triggered by a measurement performed on the *imaginary* particle. In contrast, using

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"superposition (disjunction)" to describe *different* particles of the same kind measured in *different* repetitions of the corresponding experiment, the completed quantum theory precludes inexplicable collapses of wave-functions and does imply the falsity of Heisenberg's uncertainty relation.

In the optical experiment with *single* pairs of *correlated* photons [9], the pairs are described by the "entangled state" expressed as a superposition (conjunction). For a pair of correlated photons described by the "entangled state", no polarization can be assigned to the photons if no measurement is performed, and a measurement triggers an abrupt collapse of the "entangled state" [9]. The "entangled state" cannot describe anything physically meaningful in the real world.

By contrast, corresponding to the polarizations *simultaneously* assigned to both correlated photons in a *single* pair to be detected jointly in the real world, each *single* outcome is obtained in *one* repetition of the experiment, even though the precise space coordinates used to detect the pair are unattainable by measurements and unknown. Violating the general principle of measurements brings about using an *imaginary* pair to characterize *different* pairs detected in *different* repetitions of the experiment. Consequently, *correlations* in Einstein's local-realist world view are confused with "nonlocal-interactions" in the world described by Bell's theorem used to prove Einstein wrong. The confusion must be clarified.

5. Correlation versus Nonlocal-Interaction

The *correlations* between *distant* components of the combined system in Einstein's local-realist description of the world differ essentially from "nonlocal-interactions" in the world described by Bell's theorem used to interpret the experimental results of testing Bell inequalities, where the combined system is measured in *one* repetition of a given experiment. The general principle of measurements can reveal the difference. Consider the experimental tests of Bell inequalities with *single* pairs of *correlated* photons. According to [24], the "locality loophole" has been closed, which is relevant to the Einstein-Bohr debate. Other loopholes, such as those concerning detections of photons and various far-fetched interpretations of Bell's theorem, are not fundamental. Detection loopholes cannot disprove Bell's theorem or change the world it describes. Far-fetched interpretations of Bell's theorem are not the experiments themselves and will not be considered here.

As implied by a condition necessary to observe any random phenomenon, the *correlations* in Einstein's local-realist description of the world are *deterministic*. The necessary condition is a banal fact: any single measurement makes no sense statistically. Clearly, jointly detecting the correlated photons in a *single* pair will produce *one and only one* outcome in *one* repetition of the corresponding experiment; randomness cannot manifest itself in only one repetition. Thus the polarizations can be *simultaneously* assigned to *both* correlated photons in each pair to be detected jointly, and the *correlations* between the photons in the single pairs must be *deterministic*. Therefore, "superposition (disjunction)" used to describe the single pairs precludes collapses of "entangled states" triggered by measurements. Compared to the *deterministic correlations*, "nonlocal-interactions" imply the legitimacy of "entangled states", which amounts to presuming the legitimacy of the current quantum theory. Without "nonlocal-interactions", Bell's theorem cannot interpret the experimental results of testing Bell inequalities, which are expressed in terms of *statistical* correlations. But why are the *deterministic correlations* mistaken for "nonlocal-interactions"? There are three reasons.

First, Bell and his followers did not attempt to explain random phenomena in outcomes obtained by experiments involving superpositions (conjunction); they merely tried to "reinterpret quantum mechanics in terms of a statistical account of an underlying hidden-variables theory" [10], keeping quantum mechanics in its current form intact. To reproduce the *statistical* predictions of quantum mechanics, Bell inequalities have to be expressed by *statistical* correlations. Secondly, the condition necessary to observe random phenomena is ignored. According to this condition, randomness cannot manifest itself in only *one* repetition of the corresponding experiment. Finally, "entangled states" used in the experimental tests of Bell inequalities violate the general principle of measurements. Consequently, an *imaginary* pair is used to characterize *different* pairs detected in *different* repetitions,

 doi:10.20944/preprints202503.0798.v1

and *mutually exclusive* properties corresponding to *different* outcomes are attached to the *imaginary* pair. Eventually, *deterministic correlations* are mistaken for "nonlocal-interactions".

6. Discussion

Inspired by Einstein, Bell and his followers intended to complete quantum mechanics within the framework of local realism [5,11]. However, misguided by the nonexistent linkage between hidden variables and elements of physical reality, they adopted a problematic approach, which cannot reveal the essential difference between *deterministic correlations* in Einstein's local-realist description of the world and "nonlocal-interactions" in the world described by Bell's theorem. This regrettable situation might have been avoided, had they focused on explaining randomness in quantum physics rather than reinterpreting the current quantum theory. Described himself as a follower of Einstein, Bell hoped for better theories than our current quantum theory, insisting that the current theory was no more than a temporary expedient [5]; he would have been happy to see quantum mechanics completed within the framework of local realism.

By explaining randomness in quantum physics, the general principle of measurements allows quantum mechanics to be completed within the framework of local realism while keeping the axiomatic definition of a *general* Hilbert space essentially unchanged. In the axiomatic formulation of quantum mechanics, only the axioms concerning various calculations in quantum mechanics are necessary. Using disjunction ("or") as the logical relation between superposed orthonormal vectors, the completed quantum theory precludes inexplicable collapses of wave-functions and is intuitively comprehensible, thus alleviating much difficulty in understanding quantum mechanics experienced by many people, including Bell [11]. The general principle of measurements can also reveal the essential difference between *deterministic correlations* and "nonlocal-interactions". Among various world views, Einstein's local-realist world view is correct.

Funding: This research received no funds or grants.

Data Availability Statement: No datasets were generated or analyzed.

Conflicts of Interest: The author declares no conflicts of interest.

References

1. Einstein, A.; Podolsky, B.; Rosen, N. Can quantum-mechanical description of physical reality be considered completed? *Physical Review* **1935**, *47*, 777–780. https://doi.org/10.1103/PhysRev.47.777.
2. Bohr, N. Can quantum-mechanical description of physical reality be considered complete? *Physical Review* **1935**, *48*, 696–702. https://doi.org/10.1103/PhysRev.48.696.
3. *The Born-Einstein Letters*; MACMILLAN: London, 1971.
4. Jammer, M. *The Philosophy of Quantum Mechanics*; John Wiley & Sons: New York, 1974.
5. Whitaker, A. John Bell and the most profound discovery of science. *Physics World* **1998**, *11*, 29.
6. Bell, J.S. On the Einstein-Podolsky-Rosen paradox. *Physics* **1964**, *1*, 195–200. https://doi.org/10.1103/PhysicsPhysiqueFizika.1.195.
7. Clauser, J.F.; Horne, M.A.; Shimony, A.; Holt, R.A. Proposed experiment to test local hidden variable theories. *Physical Review Letters* **1969**, *23*, 880–84. https://doi.org/10.1103/PhysRevLett.23.880.
8. Aspect, A. Bell's inequality test: more ideal than ever. *Nature* **1999**, *398*, 189–190. https://doi.org/10.1038/18296.
9. Aspect, A. Bell's theorem: the naive view of an experimentalist. In Proceedings of the Quantum [Un]speakables-From Bell to Quantum information; Bertlmann, R.; Zeilinger, A., Eds., Berlin, 2002.
10. Clauser, J.F.; Shimony, A. Bell's theorem: experimental tests and implications. *Reporting Progress Physics* **1978**, *41*, 1881–1927. https://doi.org/10.1088/0034-4885/41/12/002.
11. Bell, J.S. On the impossible pilot wave. *Foundations of Physics* **1982**, *12*, 989–999.
12. Hance, J.R. Counterfactual restrictions and Bell's theorem. *Journal of Physics Communicacctions* **2024**, *8*. https://doi.org/10.1088/2399-6528/ad9b6d.
13. A.J.Leggett. The Quantum Measurement Problem. *Science* **2005**, *307*, 871–872. https://doi.org/10.1126/science.1109541.

 doi:10.20944/preprints202503.0798.v1

14. Hance, J.R.; Hossenfelder, S. What does it take to solve the measurement problem? *Journal of Physics Communicacctions* **2022**, *6*. https://doi.org/10.1088/2399-6528/ac96cf.
15. Maudlin, T. What Bell did. *Journal of Physics A: Mathematics and Theory* **2014**, *47*, 424010.
16. Christian, J. *Disproof of Bell's Theorem: Illuminaing the Illusion of Entanglement*; Brown Walker Press: Boca Raton,FL USA, 2014.
17. Hess, K. A Critical Review of Works Pertinent to the Einstein-Bohr Debate and Bell's Theorem. *Symmetry* **2022**, *14*, 163.
18. Bohm, D. A suggested interpretation of the quantum theory in terms of 'hidden variables'. *Physical Review* **1952**, *85*, 166–93. https://doi.org/10.1103/PhysRev.85.166.
19. Bell, J.S. Introduction to the hidden-variable question. In Proceedings of the Foundations of Quantum Mechanics; d'Espagnat, B., Ed., New York, 1971; pp. 171–81.
20. Bell, J.S. On the Problem of Hidden Variables in Quantum Mechanics. *Reviews of Modern Physics* **1966**, *38*, 447–452.
21. Bell, J.S. Bertlmann's socks and the nature of reality. *Journal de Physique* **1981**, *42(C2)*, C41–C62. https://doi.org/10.1051/jphyscol:1981202.
22. Bell, J.S. Einstein-Podolsky-Rosen experiments. In Proceedings of the Proceedings of the Symposium on Frontier Problems in High Energy Physics, Pisa, June 1976; pp. 33–45.
23. Feynman, R. *The Character of Physical Law*; MIT Press: Cambridge, MA, 1965.
24. Aspect, A. Closing the door on Einstein and Bohr's quantum debate. *Physics* **2015**, *8*, 123. https://doi.org/10.1103/Physics.8.123.