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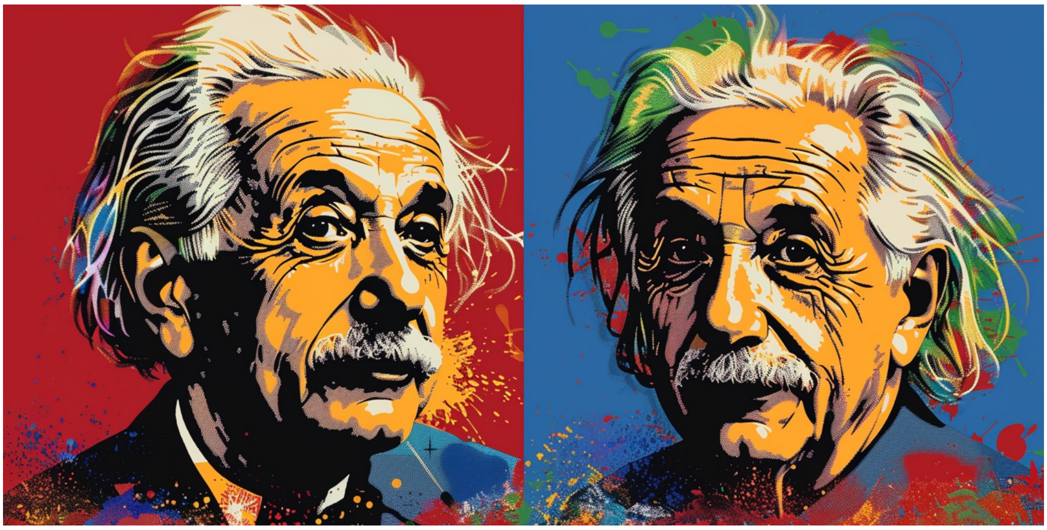

On Purported Physical Realizations of So-called Quantum Information Technologies

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Abstract

Considered by Einstein as “the fundamental dice-game”, the quantum-mechanical description of microscopic objects is controversial. The controversy mainly concerns the notion of “quantum superposition” in current quantum theory. According to Einstein’s understanding of the physical world, the quantum-mechanical description is incomplete; nevertheless, rendering quantum mechanics complete might be possible. Derived by resorting to a hidden-variable theory, Bell inequalities attempted to complete quantum mechanics, but the attempts all failed. According to Bell’s theorem, at least one of two fundamental hypotheses for scientific research, namely, realism and locality, must be abandoned, which opened the door to so-called quantum information technologies. Consequently, such technologies all stem from “the fundamental dice-game”. This paper shows that, Bell’s theorem is false, while Einstein’s understanding of the physical world is correct; based on “quantum superposition”, quantum information technologies are all fictitious results in “the fundamental dice-game” and hence physically unrealizable. A very regrettable conclusion then follows inevitably: An extremely huge amount of time, effort, funding, and investment in realizing physically unrealizable quantum information technologies has been wasted because of “the fundamental dice-game”, which has seriously damaged not only physics but also all other sciences!

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1. Introduction

Since the inception of quantum mechanics, its conceptual foundations have been controversial[1][2][3], and are still debatable even today. Einstein considered the quantum-mechanical description of microscopic objects in the physical world as "the fundamental dice-game" [4]. Based on the notion of "quantum superposition" in current quantum theory, the quantum-mechanical description denies the objective existence of definite properties of microscopic objects prior to measurements or observations, which contradicts Einstein's understanding of the physical world. According to Einstein's understanding, before we can describe a microscopic object reasonably by measuring or observing its properties, the properties must exist independently of human consciousness; in the sense above, the quantum-mechanical description is incomplete, but rendering quantum mechanics complete might be possible [1].

Derived by resorting to a hidden-variable theory, Bell inequalities attempted to render quantum mechanics complete[5][6]. However, the attempts all failed when tested by experiments against quantum mechanics [7][8][9][10][11][12]. According to Bell's theorem [13][14], the failure of Bell inequalities confirmed the legitimacy of the quantum-mechanical description of the physical world, and at least one of two fundamental hypotheses for scientific research, namely, realism and locality, must be abandoned. Renouncing either or both of the hypotheses opened the door to so-called quantum information technologies [15][16][17][18][19][20][21][22]. Consequently, such technologies all stem from what Einstein called "the fundamental dice-game" in quantum mechanics [4]. Nowadays, most physicists consider Einstein wrong. However, the disagreements with Einstein's point of view actually result from the erroneous explanations of the measurement outcomes observed in the experiments with microscopic objects. Such objects are all described by "quantum superposition" in the Hilbert space that serves as the mathematical setting of quantum physics.

Needless to say, the Hilbert space is necessary to describe microscopic objects. In this mathematical sense, we may say "a microscopic object studied in quantum physics lives in the Hilbert space". However, the physical world consists of physical objects, not their mathematical descriptions. Physically, any microscopic object can only exist in the real world rather than in the Hilbert space. Actually, laboratories in the real world are the only places where experimental physicists can measure microscopic objects by experiments. In the real world, the model of space is the three-dimensional Euclidean space and the model of time is the set of nonnegative real numbers. As a mathematical fact irrelevant to anything about instruments used for making measurements in practice or accuracies of measurement outcomes, *precise space and time coordinates are practically unattainable by measurements*. Here space coordinates are *irrelevant* to positions of physical objects in space; the coordinates correspond to directions along which the objects move in space or orientations of apparatuses used to measure the objects. The above fact reflects an important principle regarding the nature of measurements in general, referred to as the *principle of measurements* in this paper. When measuring macroscopic objects studied in classical physics, we hardly notice the principle of measurements and hence can safely ignore it. In contrast, when experimental physicists measure microscopic objects studied in quantum physics, this principle may be annoying and unwelcome because it is no longer ignorable and will remain unchanged forever, although the measurement accuracies can always be improved. Unfortunately, the Hilbert space in quantum mechanics is founded on the postulate of quantum superposition formulated without considering the principle of measurements. Misguided by the problematic postulate, experimental physicists might take precise space and time coordinates for granted and hence violate this principle when explaining the measurement outcomes observed in the laboratories. It is the problematic postulate of quantum superposition that leads to “the fundamental dice-game” in quantum mechanics.

The main findings reported in this paper are as follows: Bell’s theorem is false, while Einstein’s understanding of the physical world is correct; the quantum-mechanical description of microscopic objects in the physical world is indeed incomplete and it is possible to complete quantum mechanics without resorting to any hidden-variable theory while keeping the Hilbert space in quantum mechanics essentially unchanged; stemming from “the fundamental dice-game”, quantum information technologies are all physically unrealizable. Because all such technologies are based on the notion of “quantum bits”, if quantum bits are physically unrealizable, none of such technologies can be realized physically. Therefore, to show that quantum information technologies are all physically unrealizable, it is sufficient to show that quantum bits are not physically realizable *in principle*. As we shall see, the purported physical realizations of quantum bits are fictitious results in “the fundamental dice-game” based on the postulate of quantum superposition in current quantum theory; they do not really exist in the physical world.

In the rest of this paper, Section 2 introduce the principle of measurements and demonstrates its applications to quantum physics. Section 3 explains why Bell’s theorem is false, while Einstein’s understanding of the physical world is correct and hence the failure of Bell inequalities has nothing to do with locality and realism. Section 4 shows the falsity of a bold, fundamental assumption adopted by quantum information theorists and reveals the connection between the false assumption and the problematic postulate of quantum superposition. Section 5 proposes a feasible way to complete quantum mechanics by modifying the meaning of “quantum superposition”. Section 6 further elucidates, with examples, why quantum bits and hence quantum information technologies are physically unrealizable. Section 7 discusses briefly the relation between quantum information technologies and our understanding of the physical world, and then concludes the paper with a summary of the reported findings.

2. Principle of Measurements

Experimental physicists, just like laymen, all live in the real world. Consequently, they can only measure physical quantities in space and time of the real world, not anywhere else. Measuring physical quantities needs mathematical models of space and time, respectively, in the real world. The mathematical model of time elapsed in the real world is the set R_0 of nonnegative real numbers. Each element of R_0 represents a precise time coordinate. Denote by R_+ the set of positive real numbers. The set R_0 and the metric defined by the usual distance function between two nonnegative real numbers form a metric topological space, with the collection of all open subsets of R_+ constituting a metric topology. It is easy to see that no $t \in R_+$ can serve as an isolated point of R_0. Consider a subset $S(t) \subset R_0$ with $t \in S(t)$. For an open interval $B(t, r) = (t - r, t + r)$ and for each sufficiently small $r \in (0, t)$,

$$S(t) \cap B(t, r) = B(t, r) \neq \{t\}.$$

Consequently, R_0 has no isolated point.

The mathematical model of space in the real world is the three-dimensional Euclidean space endowed with the metric defined by the usual distance function. Each point in the Euclidean space has its unique and precise coordinates. The Euclidean space and the corresponding metric form a metric topological space, with the family of all open subsets of the Euclidean space constituting the corresponding metric topology. Similar to the set R_0, the Euclidean space has no isolated point.

Measuring the coordinates of a point in the Euclidean space perfectly precisely requires that the point must be an isolated point. Similarly, unless an instant of time corresponds to an isolate point in the set R_0, it is impossible to measure its coordinate perfectly precisely. We have just seen an important mathematical fact: Neither the Euclidean space nor the set R_0 has isolated points. This fact reflects a principle regarding the nature of measurements in general, referred to as the "**principle of measurements**":

- *Precise space and time coordinates are practically unattainable by measurements*

Irrelevant to any issue about measurement instruments or accuracies of measurement outcomes, the principle of measurements can account for unpredictability or randomness exhibited in the outcomes of measuring microscopic objects studied in quantum physics. The microscopic objects are typically described quantum-mechanically by "quantum superposition". Such quantum-mechanical description takes precise space and time coordinates for granted and hence violates the principle of measurements. Consequently, "quantum superposition" is invalid and illegitimate for describing microscopic objects in the real world.

For example, consider single pairs of correlated photons for testing the CHSH inequality in the optical Bell experiment[8]. Derived by Clauser, Horne, Shimony and Holt [7], the CHSH inequality is a generalization of Bell's original inequality[5]. The pairs are quantum-mechanically described by the so-called "entangled state" given in the form of "quantum superposition". Photons in the same pair propagate in opposite directions along a fixed z-axis. The linear polarization directions are specified by the x-axis and the y-axis. Taking the precise space coordinates corresponding to the desired propagating direction and polarization directions for granted, the "entangled state" violates the principle of measurements and hence is invalid and illegitimate. The unpredictable or random outcomes observed in the optical Bell experiment can be explained by the principle of measurements as demonstrated below.

To detect the photons in the optical Bell experiment, the propagating directions and orientations of polarizers for measuring the linear polarizations of the photons must be specified. Any direction or orientation in space corresponds to a unique point on a unit sphere. The sphere is a subset of the Euclidean space. It is worth noting the following fact:

- *The coordinates of points on the unit sphere are irrelevant to spatial positions of microscopic objects and hence will not appear in the mathematical expressions of the corresponding quantum states*.

It is also worth noting that, the outcome obtained by measuring a single pair cannot reflect randomness or unpredictability. The unpredictability or randomness can only manifest itself in a large number of measurement outcomes obtained in *different* repetitions of the corresponding experiment under purportedly the same experimental condition. Each detected pair corresponds to only one outcome measured in a repetition. This is one of typical circumstances in which the principle of measurements is not ignorable.

For pairs of *perfectly correlated* photons detected in the optical Bell experiment[8], the orientations of two spatially separated polarizers are parallel. At each polarizer, the detected photons had purportedly the same (desired) polarization direction, followed purportedly the same (desired) propagating direction, and detected by the polarizer with purportedly the same (desired) orientation. Consider the precise space coordinates corresponding to the following directions and orientations.

a. The *desired* same propagating direction and the *desired* same polarization direction, purportedly specified for each photon.
b. The *actual* propagating direction and the *actual* polarization direction of each photon.
c. The *desired* same orientation of the polarizer, purportedly specified for measuring each photon.
d. The *actual* orientation for measuring each photon.

The principle of measurements is not ignorable anymore here. Consequently, the space coordinates corresponding to the directions and orientations listed above are all unattainable by measurements and hence *unknown*. The *actual* propagating directions of *different* photons are almost surely different, the *actual* polarization directions of *different* photons are almost surely different, and the *desired* orientation and the *actual* orientations for measuring *different* photons are also almost surely different. Three tiny volumes serve as the approximations to the precise space coordinates. The first volume contains the coordinates of desired and actual propagating directions, the second contains those of desired and actual polarization directions, and the third contains those of desired and actual orientations of the polarizer.

In the optical Bell experiment[8], taking precise space coordinates for granted violated the principle of measurements and resulted in using an *imaginary* single pair of correlated photons to characterize *different*, purportedly identically prepared pairs. Violating the principle of measurements has caused serious consequences, such as the erroneous explanation of the experimental results and the renouncement of either or both of locality and realism. As shown above, the unpredictability exhibited in the outcomes of measuring the polarizations of perfectly correlated photons is not intrinsic; it can be explained reasonably by the principle of measurements.

For a particle moving in space, the mathematical expression of its quantum state, given in the form of “quantum superposition”, depends on time and spatial position of the particle explicitly. In such circumstances, violating the principle of measurements will also cause serious consequences. As an example, consider a coherent superposition of energy eigenstates of the particle. According to quantum mechanics in its current form, before a measurement is performed to measure the energy of the particle, the particle is in more than one energy states at the *same* time.

Evidently, the outcome obtained by measuring a single particle cannot reflect randomness or unpredictability. The unpredictability or randomness can only manifest itself in a large number of measurement outcomes obtained in *different* repetitions of the corresponding experiment under purportedly the same experimental condition. Each measured particle corresponds to only one outcome obtained in a repetition of the experiment at purportedly the same *desired* instant *t*. As an approximation to the specified coordinate of the *desired* instant *t*, a tiny time interval contains both the *unknown* coordinate of the *desired* instant *t* and the *actual and unknown* coordinates of almost surely *different* instants at which *different* particles in *different* repetitions are measured.

Taking the precise time coordinate of *t* for granted will violate the principle of measurements. The violation will result in using an *imaginary* particle purportedly measured at the desired instant *t* to characterize *different* particles of the same kind, measured at almost surely *different* instants in *different* repetitions, which will eventually lead to the erroneous explanation of the unpredictability implied by current quantum theory.

Instead of measuring energy, investigating the spatial position of the particle at a *given* time requires repeating the above procedure for all possible spatial positions of the particle. Quantum mechanics in its current form claims that, until and unless a measurement is performed to measure the position of the particle in space, the particle is at uncountably infinite many different positions at the *same* time. Now it is not difficult to see the falsity of this claim; the claim is wrong because it violates the principle of measurements!

3. Einstein’s Understanding of Physical World

In the physical world as understood by Einstein, locality and realism are necessary for anything to be physically meaningful. Based on “quantum superposition”, the quantum-mechanical description of the physical world differs essentially from Einstein’s point of view. According to Bell’s theorem, the failure of Bell inequalities indicates that either or both of locality and realism must be wrong and hence at least one of the hypotheses must be abandoned. However, the failure of Bell inequalities does not necessarily justify giving up either of the hypotheses. Renouncing either or both of the hypotheses actually results from the widely accepted but erroneous explanation of the measurement outcomes observed in Bell experiments devised for testing Bell inequalities.

Bell inequalities are all derived by resorting to a hidden-variable theory for *reinterpreting* quantum mechanics [8][13]. Reinterpreting quantum mechanics actually presumes the basic notions of current quantum theory, such as “quantum superposition”. As we can readily see below, Bell inequalities miss the essence of the famous argument of Einstein, Podolsky, and Rosen (henceforth EPR) presented in their celebrated paper [1]. The essence is whether it is legitimate to describe microscopic objects in the real world based on “quantum superposition”. As shown in Section 2, the quantum-mechanical description of the physical world violates the principle of measurements and hence “quantum superposition” is invalid and illegitimate. However, although “quantum superposition” is invalid and illegitimate, this notion plays two closely related roles in various experiments devised for measuring microscopic objects: One is to describe microscopic objects to be measured; the other is to explain the measurement outcomes observed. This twofold role of “quantum superposition” may explain why the probabilistic predictions of quantum mechanics are always correct; however, the correctness of the quantum-mechanical predictions conceals, unfortunately, the invalidity and illegitimacy of “quantum superposition”.

Clearly, Einstein questioned the legitimacy of using “quantum superposition” to describe the physical world[1]. In contrast, even though Bell inequalities do not involve any notion in quantum theory while merely trying to reinterpret quantum mechanics by resorting to a hidden-variable theory, the reinterpretation fails to consider the basic issue raised by EPR [1], namely, whether using “quantum superposition” to describe the physical world is legitimate or not [8][13]. Although “quantum superposition” is invalid and illegitimate, experimental physicists rely on quantum-mechanically described microscopic objects not only for testing Bell inequalities but also for interpreting the experimental results. Consequently, so long as the microscopic objects are described quantum-mechanically by using invalid and illegitimate “quantum superposition”, the failure of Bell inequalities is inevitable even before Bell experiments are actually performed, no matter how Bell inequalities are derived and regardless of the assumptions underlying their derivations. Thus invalid and illegitimate “quantum superposition” and its twofold role imply not only the failure of Bell inequalities but also the falsity of Bell’s theorem.

To be specific, consider the optical Bell experiment[8] devised to test the CHSH inequality. Quantum-mechanically described by the so-called “entangled state” given in the form of “quantum superposition”, microscopic objects for testing the CHSH inequality are single pairs of correlated photons. As elucidated in Section 2, the “entangled state” is invalid and illegitimate because it takes precise space coordinates for granted and hence violates the principle of measurements. Although the “entangled state” is invalid and illegitimate, the pairs of correlated photons are quantum-mechanically described by the “entangled state” not only for testing the CHSH inequality but also for explaining the experimental results. Deep-rooted in the optical Bell experiment, the invalid and illegitimate quantum-mechanical description goes with every single pair of correlated photons. This indicates clearly why the CHSH inequality failed when tested against quantum mechanics by the optical Bell experiment.

Now we can see clearly, the failure of the CHSH inequality is already predetermined by the notions in current quantum theory, such as “quantum superposition” and “quantum entanglement”; their legitimacy was questioned by EPR and should have been tested by the optical Bell experiment; however, it is instead presumed by reinterpreting quantum mechanics based on a hidden-variable theory. Similarly, from invalid and illegitimate “quantum superposition” and its twofold role in various experiments devised for measuring microscopic objects, we can also see why all quantum information technologies are merely illusive results in “the fundamental dice-game”.

Therefore, invalid and illegitimate “quantum superposition” presumed by the reinterpretation are actually responsible for the failure of Bell inequalities. In other words, the failure of Bell inequalities is irrelevant to locality and realism; Einstein’s understanding of the physical world is correct! We are still living in the world as understood by Einstein, and can still keep locality and realism as our fundamental hypotheses for scientific research.

4. False Assumption in Quantum Information

In the Hilbert space for describing microscopic objects, unit vectors represent “pure quantum states”. All vectors with unit norm and different only by a phase factor in the Hilbert space are the same pure state; their collection is a “ray”. Thus a ray represents a pure state. Because the Hilbert space is a vector space, the superposition principle allows experimental physicists to obtain a pure state from other pure states: if two pure states do not belong to the same ray, their properly normalized superposition is also a pure state.

To show that quantum bits are not physically realizable in principle, it is sufficient to show that their candidates, given by “quantum superposition” of two-level systems, do not exist in the physical world. The superposed states in “quantum superposition” are pure states, namely, orthonormal vectors in the Hilbert space. By focusing on pure states, we can avoid distractions such as “mixed states” (or “statistical mixtures”), which do not exist in the physical world either.

According to current quantum theory, as a theoretical notion, a quantum system does not really exist in the physical world [23]. By definition, a quantum system is an equivalence class of “preparations”, namely, a set of instructions. Experimental physicists follow the instructions when they perform “tests” in their experiments for observing quantum phenomena by measuring microscopic objects of the same kind. The terms “preparations” and “tests” are primitive notions of quantum theory in its current form. The intuitive meanings of the terms are as follows.

A “preparation” is a completely specified experimental procedure, and a “test” includes a preparation and a final step of the experiment. The final step produces the outcome of the test. One test yields one outcome. To obtain sufficiently many outcomes, a large number of repetitions of the corresponding experiment is necessary. The outcomes produced by identically prepared, different tests may not necessarily be identical; they are unpredictable or random, but statistically predictable with definite probabilities. The following is a bold, fundamental assumption adopted by quantum information theorists [23].

- Every vector (except the null vector) in the Hilbert space represents a physically realizable pure state, and hence quantum bits are physically realizable.

However, this assumption is false and misleading. The assumption is false, not only because it is impossible to design equipment in the real world for preparing a quantum system in a pure state represented by “quantum superposition”, but also because “quantum superposition” is invalid and illegitimate for describing microscopic objects in the real world, as elucidated in Section 2. The assumption is misleading because it is based on a misleading analogy between the ordinary three-dimensional Euclidean space and the Hilbert space; the former is the model for describing macroscopic objects studied in classical physics, but the latter is the model for describing microscopic objects studied in quantum physics.

According to the analogy, the orthonormal vectors in the Hilbert space are analogous to the unit vectors along a set of orthogonal axes in Euclidean space . Such an analogy is misleading because the orthonormal vectors in the Hilbert space correspond to the superposed states, and according to the postulate of quantum superposition in current quantum theory, the orthonormal vectors represent mutually exclusive properties of the same microscopic object at the same time before measurements or observations; in contrast, the orthogonal vectors in Euclidean space do not represent mutually exclusive properties of any macroscopic object.

Because “quantum superposition” is invalid and illegitimate, by no means can current quantum theory supply instructions for actually setting up laboratory procedures to prepare a quantum system in a *pure state* represented by “quantum superposition”. Current quantum theory, instead, merely provides a way to calculate probabilities for the outcomes obtained by measurements in the experiment with purportedly identically prepared microscopic objects. Here we see the twofold role of “quantum superposition” again: Although “quantum superposition” is invalid and illegitimate, the microscopic objects are described quantum-mechanically by the pure state given in the form of “quantum superposition” not only for measuring the microscopic objects but also for explaining the measurement outcomes. This is exactly the same patten in the optical Bell experiment as shown in Section 2. In the optical Bell experiment, the single pairs of correlated photons are quantum-mechanically described by the so-called “entangled state” given in the form of “quantum superposition” not only for testing the CHSH inequality but also for explaining the experimental results. The twofold role of “quantum superposition” may explain why the calculated probabilities for the outcomes are always correct; however, the correctness of the calculated probabilities conceals, unfortunately, the fact that quantum bits are merely illusive results in “the fundamental dice-game” based on invalid and illegitimate “quantum superposition”.

Misguided by the false and misleading assumption, quantum information theorists are content with the conceived laboratory procedures, which only exist in their *imagination*, and use whatever is available in current quantum theory to *analyze, a posteriori*, their claimed physical realizations of quantum bits. Various advantages of quantum information technologies over the corresponding classical counterparts then follow from such analysis based on the false assumption.

The false assumption results from the postulate of quantum superposition. In current quantum theory, the formulation of this postulate fails to consider the principle of measurements. Although all available experiments have already confirmed the correctness of the probabilistic predictions given by quantum mechanics, without considering the principle of measurements, the postulate of quantum superposition cannot tell us why the measurement outcomes are unpredictable or random rather than definite or deterministic. According to the widely accepted explanation, the measurement outcomes are intrinsically unpredictable and hence quantum mechanics is intrinsically probabilistic. However, this explanation is wrong. The unpredictability or randomness can be explained reasonably by the principle of measurements as shown in Section 2. The measurement outcomes are not intrinsically unpredictable, and quantum mechanics is not intrinsically probabilistic. Violating the principle of measurements results in the problematic postulate of quantum superposition, and the problematic postulate then leads to the false assumption. To find a way out, it is necessary to modify the meaning of “quantum superposition”. By doing so, it is possible to complete quantum mechanics without resorting to any hidden-variable theory, and meanwhile, the mathematical setting for quantum physics can remain essentially unchanged.

5. Modifying "Quantum Superposition"

The principle of measurements paves the way for us to render quantum mechanics complete within the framework of the Hilbert space for describing microscopic objects without resorting to any hidden-variable theory. The Hilbert space is the mathematical setting of quantum physics. According to the postulate of quantum superposition in current quantum theory, before measurement or observation, a quantum object described by the notion of "quantum superposition" is *simultaneously* in each orthonormal state, and hence possesses mutually exclusive properties at the*same time*. In other words, the logical relation between the superposed orthogonal vectors is conjunction.

The formulation of the postulate of "quantum superposition" is based on measurement outcomes obtained in*different* repetitions of the corresponding experiment. Taking precise space and time coordinates for granted, the formulation violates the principle of measurements. Consequently, *different* quantum objects of the same kind measured in*different* repetitions purportedly under the same experimental condition are confused with an *imaginary* quantum object. Corresponding to the mutually exclusive properties, the outcomes actually belong to *different* quantum objects of the same kind measured in *different* repetitions while having nothing to do with the*imaginary* object. Therefore, it is not legitimate to use conjunction as the the logical relation between the superposed orthonormal vectors in the Hilbert space for describing any *given* microscopic object. Whether or not a measurement is performed on the object, the logical relation between the orthonormal vectors must be disjunction if such vectors represent mutually exclusive properties simultaneously belonging to the *same* object.

The use of disjunction as the logical relation between the orthonormal vectors not only can be justified by the principle of measurements; it is also consistent with the general definition of Hilbert space. In fact, the concepts for defining a Hilbert space in general are all highly abstract and have no practical meanings. Orthogonality specified by an inner product is the most important concept to define a Hilbert space. The orthogonality for defining a Hilbert space in general is a purely mathematical concept without geometric or any other practical meaning. Assigning practical meanings to the orthogonality is unnecessary. Moreover, for a Hilbert space in general, it is even unnecessary to specify the logical relation between orthogonal vectors. For a given application, practically meaningful concepts are necessary to define a specific Hilbert space for describing a practically meaningful object, and conjunction may serve as the logical relation between orthogonal vectors in the specific Hilbert space; however, the orthogonal vectors must not correspond to mutually exclusive properties *simultaneously* belonging to the object. In fact, the logical relation between orthogonal vectors in a specific Hilbert space can also be disjunction, or even neither conjunction nor disjunction.

Example 1. With the inner product defined for the Euclidean vectors, the Euclidean space is a Hilbert space. For this Hilbert space, the orthogonal Euclidean vectors do *not* represent mutually exclusive properties *simultaneously* belonging to any geometric object, and the logical relation between the orthogonal vectors is conjunction.

Example 2. The classical prototype of a Hilbert space was first studied by D. Hilbert with applications to the theory of integral equations. This Hilbert space consists of infinite sequences of complex numbers. The logical relation between the orthogonal vectors is neither conjunction nor disjunction. It is not necessary to specify the logical relation.

Now consider again the Hilbert space in quantum mechanics. According to the principle of measurements, the different outcomes obtained in *different* repetitions of the experiment are irrelevant to the*imaginary* single object and actually belong to *different* quantum objects of the same kind, and hence each of the outcomes corresponds to a definite property of the physical reality belonging to the corresponding quantum object; the definite property exists independently of human consciousness. Consequently, a definite value corresponding to the outcome can be *assigned* to the object, even though we are not aware of the precise space and time coordinates for measuring it; the value can even be an element of a continuum and hence cannot be obtained by measurements, such as the position or momentum of a particle moving in space. Therefore, after modifying the meaning of “quantum superposition” by using disjunction as the logical relation between the superposed orthonormal vectors, we can indeed render quantum mechanics complete within the framework of Hilbert space without resorting to any hidden-variable theory!

After rendering quantum mechanics complete in the way proposed above, there will be two entirely different notions of “quantum superposition”. In the two notions, conjunction and disjunction serve, respectively, as the logical relation between the superposed orthonormal vectors. To avoid confusion, the notions will be referred to as “superposition (conjunction)” and “superposition (disjunction)”.

6. Unrealizable Quantum Bits: Examples

To elucidate further why quantum bits and hence quantum information technologies are not physically realizable, we can roughly divide quantum objects described by quantum bits into two categories, according to whether experimental physicists can measure the quantum objects at most only once or repeatedly.

1. Experimental physicists can measure quantum objects in this category at most only once.
2. Physicists can measure a quantum object in this category repeatedly.

According to quantum information theory, quantum bits are represented by “quantum superposition” of two-level systems in pure states, which are “superpositions (conjunction)”. Category (1) includes individual quantum objects, such as photons or particles. A single quantum bit for describing a quantum object in this category has a geometric representation, which is a three-dimensional unit sphere called the Bloch sphere [16]. Quantum information theorists use this geometric representation to illustrate various operations (in their *imagination*) performed on the single quantum bit. However, the Bloch sphere is not a subset of the three-dimensional Euclidean space and has nothing to do with any actual measurement of the single quantum object in the real world. As we all know, the mathematical model of space in the real world is the three-dimensional Euclidean space.

Consider, for example, individual photons in category (1). It is simply a banal fact that experimental physicists cannot measure any single photon more than once. However, precise but practically unattainable space coordinates might allure quantum information theorists to use an *imaginary* single photon described by “superposition (conjunction)” to characterize purportedly identically prepared but *different* individual photons. As shown in previous sections, for such photons, because “superposition (conjunction)” is invalid and illegitimate, by no means can current quantum theory supply instructions for actually setting up laboratory procedures to prepare a quantum system in a *pure state* represented by “superposition (conjunction)”. Current quantum theory, instead, merely provides a way to calculate probabilities for the outcomes obtained by measurements in the experiment with purportedly identically prepared individual photons. The twofold role of “superposition (conjunction)” may explain why quantum information theorists are content with the conceived laboratory procedures, which only exist in their *imagination*, and use whatever is available in current quantum theory to *analyze, a posteriori*, their claimed physical realization of a quantum bit for describing the*imaginary* single photon and the corresponding physical realization of optical photon quantum computers. Such analysis then leads to various advantages of optical photon quantum computers over classical computers. For the same reason, based on physically unrealizable quantum bits for describing individual photons, various quantum communication technologies are all physically unrealizable. Individual atoms are also in category (1). Described by physically meaningless “superposition (conjunction)”, the atoms are used to realize physically unrealizable quantum bits and the corresponding physically unrealizable ion trap quantum computers.

Category (2) contains composite quantum objects. Experimental physicists can repeatedly measure such objects. For example, consider a quantum object composed of non-Abelian anyons. Such a quantum object can only be constructed theoretically in two-dimensional spaces, which are subspaces of the three-dimensional Euclidean space. The construction is guided by numerical studies. Using non-Abelian quantum phases of matter, the quantum object is purportedly capable of encoding quantum bits in a non-local manner, and quantum information theorists consider such objects as promising candidates for building topological quantum computers. However, the possibility of using some specific quantum objects of this kind (i.e., Majorana fermions in two-dimensional p + ip Fermi superfluids) for topological quantum computation has already been questioned recently [24].

In addition, because the quantum object in this category can be measured repeatedly, quantum information theorists might take precise time coordinates for granted and hence violate the principle of measurements when they explain the measurement outcomes observed in *different* repetitions of the corresponding experiment. They might confuse almost surely *different* instants in *different* repetitions with a given instant, as if the outcomes were all measured at the given instant. However, physically meaningless “superposition (conjunction)” cannot describe the quantum object, although it can be measured repeatedly, because “superposition (conjunction)” is invalid and illegitimate for describing quantum objects. Even if a quantum object in category (2) exists in the real world, by no means can it be measured at exactly the *same* instant repeatedly in *different* repetitions!

Actually, corresponding to an *imaginary* object, “superposition (conjunction)” cannot describe any quantum object that exists in the real world. Replacing “superposition (conjunction)” by “superposition (disjunction)” will make all of illusive quantum bits disappear.

7. Discussion and Conclusion

Einstein mentioned “the fundamental dice-game” several times in his correspondences with Born. In a letter to Born, Einstein wrote [4]:

> *“We have become Antipodean in our scientific expectations. You believe in the God who plays dice, and I in complete law and order in a world which objectively exists, and which I, in a wildly speculative way, am trying to capture. I firmly believe, but I hope that someone will discover a more realistic way, or rather a more tangible basis than it has been my lot to find. Even the great initial success of the quantum theory does not make me believe in the fundamental dice-game, although I am well aware that our younger colleagues interpret this as a consequence of senility. No doubt the day will come when we will see whose instinctive attitude was the correct one.”*

What Einstein expressed in the letter indicates clearly his understanding of the physical world and shows why the debate concerning the conceptual foundations of quantum theory is so important for all sciences, not merely for quantum physics. Understanding the physical world incorrectly can cause serious consequences for scientific research in practice. Supported by arguments based on the principle of measurements, this paper has reported the following findings.

a. Bell’s theorem is false, while Einstein’s understanding of the physical world is correct.
b. By replacing “superposition (conjunction)” by “superposition (disjunction)”, it is possible to render quantum mechanics complete without resorting to any hidden-variable theory in a way such that Hilbert space in quantum mechanics will remain essentially unchanged, and eligible applications of quantum mechanics, which are all irrelevant to “the fundamental dice-game”, will also remain unchanged.
c. As fictitious results in “the fundamental dice-game” based on the problematic postulate of quantum superposition in current quantum theory, quantum information technologies are all physically unrealizable.

The findings then inevitably lead to a very regrettable conclusion: An extremely huge amount of time, effort, funding, and investment in realizing physically unrealizable quantum information technologies has been wasted because of “the fundamental dice-game”, which has seriously damaged not only physics but also all other sciences!

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