What is it like to be a quantum observer? And what does it imply about the nature of consciousness?

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Abstract

In collapse theories of quantum mechanics, there exist quantum observers who are observers being in a superposition of different result branches. In this paper, I analyze the mental state of a quantum observer. First, I argue that the mental state of a quantum observer is not the usual state of recording one of the results in the superposition, but it is definite. Second, I argue that the mental state of a quantum observer is determined by both the amplitudes and relative phases of the result branches of the superposition, and the mental content is composed of every result. Third, I argue that there are new mental properties which are lack for classical observers and determined by the amplitude and relative phase. In particular, the mental property determined by the amplitude may be a certain property of vividness of the mental content; the bigger the amplitude of a result branch, the more vivid the result is in the whole mental content. Finally, I argue that the new experience of a quantum observer, which violates quantum mechanics, implies that consciousness is not physically reducible or emergent but fundamental in collapse theories.

Consciousness cannot be accounted for in physical terms. For consciousness is absolutely fundamental. It cannot be accounted for in terms of anything else. — Erwin Schrödinger

1 Who is a quantum observer?

In standard quantum mechanics, it is postulated that when a quantum system is measured by a measuring device or an observer, its wave function no longer follows the linear Schrödinger equation, but instantaneously collapses to one of the wave functions that correspond to definite measurement results. As a consequence, there are no observers who are physically in a quantum superposition of brain states with different records. This conclusion is also true in Bohm's and Everett's theories. In these theories, although the wave function never collapses and the post-measurement state is a superposition of different result branches, the brain state of an observer after the measurement is definite, recording only one result.[1]

However, such strange observers exist in other quantum theories in which the mental state of an observer is determined by the whole superposition she is physically in, such as the collapse theories of quantum mechanics (Ghirardi 2016). Due to the imperfectness of wave-function collapse, the post-measurement state of an observer is a superposition of brain states with different records, although the modulus squared of the amplitude of one state is close to one in general. This leads to the well-known tails problem (Lewis 1995; Albert and Loewer 1996). Besides, since the collapse time of a single superposed state is an essentially random variable, whose value can range between zero and infinity, such observers always exist after certain measurements with a tiny probability. Finally, there may exist small brain observers, who are not like us and can be in a superposition of brain states most of the time.

I call these observers quantum observers. In other words, quantum observers are observers who are in a quantum superposition of brain states with different records. The question is: what is it like to be a quantum observer?[2] In this paper, I will try to answer this question by analyzing how the mental state of a quantum observer is determined by her wave function.

2 What the mental state of a quantum observer is not

Suppose there is an ideal x-spin observer M who measures the x-spin of a spin-1/2 system S without disturbing it. If the initial state is one where M is ready to make a measurement and S is in an x-spin up eigenstate, then after

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[1] The reason is that the brain state and the mental state of the observer are determined not by the whole superposition of different result branches, but by another definite hidden variable or one definite result branch of the superposition. Thus there are only classical observers in Bohm's and Everett's theories.

[2] A similar question has been asked in the bare theory (Albert 1992, p.124; Barrett 1999). The previous analysis of the answer to the question is based on the eigenvalue-eigenstate link in standard quantum mechanics. In this paper, I will give a new analysis.

the measurement S will be still in the x-spin up state, and M will physically record the x-spin up result and her corresponding mental state is the state of recording x-spin up. Similarly, if S is initially in an x-spin down eigenstate, then after the measurement S will be still in the x-spin down state, and M will physically record the x-spin down result and her corresponding mental state is the state of recording x-spin down. The evolution of the physical state of the composite system for these two cases can be written as:

$$\left|up\right\rangle_S \left|ready\right\rangle_M \rightarrow \left|up\right\rangle_S \left|up\right\rangle_M , \tag{1}$$

$$\left|down\right\rangle_S \left|ready\right\rangle_M \rightarrow \left|down\right\rangle_S \left|down\right\rangle_M . \tag{2}$$

Then if M begins in a ready-to-make-a-measurement state and S begins in a superposition of x-spin up and x-spin down, the post-measurement state may be

$$\alpha \left|up\right\rangle_S \left|up\right\rangle_M + \beta \left|down\right\rangle_S \left|down\right\rangle_M . \tag{3}$$

in collapse theories, where α and β are not zero and they satisfy the normalization condition $|\alpha|^2 + |\beta|^2 = 1$. The question, then, is: what is the mental state of the quantum observer M? In this section, I will first argue that the mental state of M is not the usual state of recording either x-spin up or x-spin down.

When $\alpha = \beta$, the argument is simple. By symmetry of the two terms in the superposition, the superposed state cannot describe the observer M recording either x-spin up or x-spin down. If the superposition describes the observer M recording x-spin up or x-spin down, then since the two terms in the superposition has exactly the same status, the superposition will also describe the observer M recording x-spin down or x-spin up. Since x-spin up and x-spin down are two distinct records, this leads to a contradiction.

When $\alpha \neq \beta$, this symmetry argument is not valid, and it seems possible that the observer M may have the mental state of recording x-spin up or recording x-spin down for some values of α and β. For example, one may assume that the observer M has the mental state of recording x-spin up when $|\alpha| > |\beta|$ and she has the mental state of recording x-spin down when $|\alpha| < |\beta|$ (Maudlin 1995). However, this assumption is not consistent with the general requirement of continuity for the psychophysical connection. The requirement says that when the physical state changes continuously the corresponding mental state also changes continuously. This means that when the amplitude of each branch of the superposition (3) changes continuously, the mental state of the observer M also changes continuously. But according to the above assumption, when the amplitudes of α and β change from $|\alpha| > |\beta|$ to $|\alpha| < |\beta|$, during which the change of each amplitude may be infinitesimal, the mental state of the observer M changes from the state of recording x-spin up to the state of recording x-spin down, and the change is not infinitesimal.

In the following, I will give a more general argument for the case of $\alpha \neq \beta$ based on a basic postulate about the superposition of two identical mental states. The postulate says that an observer being in a superposition of two physical states with identical mental states also has the same mental state. In short, a superposition of two identical mental states is the same mental state.

Assume the observer M in the superposition (3) or $\alpha \left|up\right\rangle_S \left|up\right\rangle_M + \beta \left|down\right\rangle_S \left|down\right\rangle_M$ has a mental state of recording x-spin up or recording x-spin down. Then consider the following two superpositions (I omit the normalization):

$$(\alpha \left|up\right\rangle_S \left|up\right\rangle_M + \beta \left|down\right\rangle_S \left|down\right\rangle_M) - \alpha \left|up\right\rangle_S \left|up\right\rangle_M \tag{4}$$

and

$$(\alpha \left|up\right\rangle_S \left|up\right\rangle_M + \beta \left|down\right\rangle_S \left|down\right\rangle_M) - \beta \left|down\right\rangle_S \left|down\right\rangle_M . \tag{5}$$

If the observer M in the superposition $\alpha \left|up\right\rangle_S \left|up\right\rangle_M + \beta \left|down\right\rangle_S \left|down\right\rangle_M$ has a mental state of recording x-spin up, then accoding to the above postulate, the first superposition will correspond to the mental state of recording x-spin up. But the first superposition is just the state $\left|down\right\rangle_S \left|down\right\rangle_M$, which corresponds to the mental state of recording x-spin down. This leads to a contradiction. Similarly, the assumption that the observer M in the superposition $\alpha \left|up\right\rangle_S \left|up\right\rangle_M + \beta \left|down\right\rangle_S \left|down\right\rangle_M$ has a mental state of recording x-spin down will also lead to a contradiction for the second superposition.

Therefore, the initial assumption is wrong, namely the mental state of the observer M being in the superposition (3) is not the usual state of recording x-spin up or recording x-spin down.

3 The mental state of a quantum observer is definite

It is usually thought that an observer in a superposition of different result states has no definite mental state (when the wave function of a system is a complete description of the system). In this section, I will argue that this view is wrong.

First of all, it seems that this view comes from the standard way of thinking. According to the eigenvalue-eigenstate link in standard quantum mechanics, a superposition of different result states, such as (3), is not a state where the observer has a definite record, either x-spin up or x-spin down or another one. However, since the eigenvalue-eigenstate link is widely argued to be problematic and is also invalid in collapse theories, this view is very likely to be wrong.

Next, it can be argued with the help of psychophysical supervenience that this view is wrong. If there are properties of definiteness and indefiniteness for a mental state, then by the principle of psychophysical supervenience each property should supervene on a corresponding physical property. As we know, the observer being in each result state has a definite mental state, and thus her mental state has the property of definiteness. Then every result state will have the same physical property on which the mental property of definiteness supervenes. Then by the superposition principle for all physical properties, the observer being in a superposition of result states will also have this physical property. This then means that the mental state of the observer being in such a superposition will also have the property of definiteness, and thus she will also have a definite mental state.

On the other hand, if there are no properties of definiteness and indefiniteness for a mental state, then it will be meaningless and also wrong to say that the observer being in a superposition of result states has no definite mental state. Instead, such a quantum obsever will also have the normal mental state as the observer being in a result state has.

Finally, it may be worth noting that there may exist another kind of understanding of the indefiniteness of the mental state of a quantum observer, that is, that an observer being in a superposition of two result states has no definite mental state means that one time her mental state is the state corresponding to one result state and the other time her mental state is the state corresponding to the other result state. But in this case, the mental state is not (uniquely) determined by or does not supervene on the whole superposition, since the same superposition may correspond to two different mental states.

4 What is it like to be a quantum observer?

I have argued that a quantum observer has no usual mental state of a classical observer, recording only one result such as x-spin up or x-spin down, while she still has a definite mental state. In this section, I will further analyze what the mental state of a quantum observer really is.

Consider a quantum observer M being in the following superposition:

$$\alpha \left|1\right\rangle_P \left|1\right\rangle_M + \beta \left|2\right\rangle_P \left|2\right\rangle_M , \tag{6}$$

where $\left|1\right\rangle_P$ and $\left|2\right\rangle_P$ are the states of a pointer being centered in positions x_1 and x_2, respectively, $\left|1\right\rangle_M$ and $\left|2\right\rangle_M$ are the physical states of the observer M who observes the pointer being in positions x_1 and x_2, respectively, and α and β, which are not zero, satisfy the normalization condition $|\alpha|^2 + |\beta|^2 = 1$. According to the previous analysis, the mental state of this quantum observer is definite, but it is neither the state of observing the pointer being in position x_1 nor the state of observing the pointer being in position x_2. Then, what does M observe when she is physically in the above superposed state?

Since the mental state of M is determined by the superposition she is physically in, what M observes may depend on both the amplitude and the phase of each branch of the superposition. Indeed, it can be readily seen from a few special cases that the mental state of M depends on the amplitude of each branch of the superposition she is physically in. When $|\alpha|^2$=1 and $|\beta|^2$=0, M will observe the pointer being only in position x_1. When $|\alpha|^2$=0 and $|\beta|^2$=1, M will observe the pointer being only in position x_2. When $|\alpha|^2 = |\beta|^2 = 1/2$, M's mental state is not the usual state of observing the pointer being in position x_1 or position x_2. However, it is not so easy to see whether the mental state of M also depends on the phase of each branch of the superposition she is physically in. Note that strictly speaking, the phase here denotes the relative phase of the two branches of the superposition, since an overall phase has no physical meaning, and two wave functions with only a difference of overall phase in fact represents the same physical state.

In the final analysis, we need to determine whether the relationship between the mental state and the wave function is an one-to-one correspondence, that is, whether different values of α/β correspond to different mental states. In order to answer this quesiton, I will resort again to the basic postulate about the superposition of two identical mental states, which says that an observer in a superposition of two physical states with identical mental states also has the same mental state.

Consider the observer M being in another superposition:

$$\alpha^{'} \left|1\right\rangle_P \left|1\right\rangle_M + \beta^{'} \left|2\right\rangle_P \left|2\right\rangle_M , \tag{7}$$

where $|\alpha|^2 + |\beta|^2 = 1$ and $\alpha^{'}/\beta^{'} \neq \alpha/\beta$, which means that this superposed state and the superposed state (6) describe different physical states. Assume when being in these two different states, the mental states of M are the same. According to the above postulate, when M is in a superposition of these two states, her mental state is the same as one of them in the superposition. Consider the following two superpositions:

$$\frac{\alpha^{'}}{\alpha}(\alpha \left|1\right\rangle_P \left|1\right\rangle_M + \beta \left|2\right\rangle_P \left|2\right\rangle_M) - (\alpha^{'} \left|1\right\rangle_P \left|1\right\rangle_M + \beta^{'} \left|2\right\rangle_P \left|2\right\rangle_M) \tag{8}$$

and

$$\frac{\beta^{'}}{\beta}(\alpha \left|1\right\rangle_P \left|1\right\rangle_M + \beta \left|2\right\rangle_P \left|2\right\rangle_M) - (\alpha^{'} \left|1\right\rangle_P \left|1\right\rangle_M + \beta^{'} \left|2\right\rangle_P \left|2\right\rangle_M). \tag{9}$$

Then when M is in these two superpositions her mental states will be the same. However, since the two superpositions are just $|2\rangle_P |2\rangle_M$ and $|1\rangle_P |1\rangle_M$, respectively, they correspond to different mental states. This leads to a contradiction. Therefore, based on the above postulate we obtain the following result, namely that when a quantum observer is in two different physical states her mental states are also different. Concretely speaking, when a quantum observer M is in the superposition (6), her mental states are different for different values of α/β.

It seems that this result is not beyond expectations. But it may have a few interesting inferences. The first one is that the mental state of M being in the superposition (6) cannot be a state whose content is empty, containing neither the content of observing the pointer being in position x_1 nor the content of observing the pointer being in position x_2. For if this is not true, then two different superpositions with different values of α/β will correspond to the same mental state, which contradicts the above result. Note that since the coefficients α and β are related to the content of observing the pointer being in position x_1 and the content of observing the pointer being in position x_2, if the mental state of M is an empty state, the state will be the same for different values of α/β.

Now there are only two possibilities. The first one is that the mental content of the observer M being in the superposition (6) contains both the content of observing the pointer being in position x_1 and the content of observing the pointer being in position x_2 for any (non-zero) value of α/β. The second one is that the mental content of the observer M being in the superposition (6) contains only the content of observing the pointer being in position x_1 or the content of observing the pointer being in position x_2 for some values of α/β. For example, the observer M has a mental content of recording x-spin up when $|\alpha| > |\beta|$ and she has a mental content of recording x-spin down when $|\alpha| < |\beta|$ (Maudlin 1995).[3]

Another inference of the above result is that the second possibility can be excluded. The reason is that if the mental content of the observer M contains only the content corresponding to one branch in the superposition, then the mental state of M will not depend on the relative phase of the two branches, since the existence of the mental property corresponding to the relative phase requires the existence of the two mental contents corresponding to the two branches. But this contradicts the above result, according to which the mental state of M depends on the value of α/β, which means that it depends not only on the amplitudes of the two branches of the superposition, but also on the relative phase of the two branches.

Now I will analyze how the mental state of the observer M is determined

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[3] Note that the mental state is composed of the mental content and other mental properties. Thus, for example, the mental state of the observer M, who has a mental content of recording x-spin up, may be not the same as the usual mental state of recording x-spin up (cf. my analysis in the second section).

by the amplitudes and relative phase of the two branches of the superposition she is physically in. As argued above, the mental content of the observer M being in the superposition (6) contains both the content of observing the pointer being in position x_1 and the content of observing the pointer being in position x_2, and how these two parts constitute the whole mental content of the observer M is determined by the values of α and β.

It seems relatively easy to conjecture how the modulus squared of the amplitude determines the mental state of the observer M. Let us see a few special cases. When $|\alpha|^2 = 1$, the mental content of the observer M is the content of observing the pointer being in position x_1. In other words, the content of observing the pointer being in position x_1 is most vividly visible. When $|\alpha|^2 = 0$, the mental content of the observer M does not contain the content of observing the pointer being in position x_1. In other words, the content of observing the pointer being in position x_1 is not visible at all. Similarly, when $|\beta|^2 = 0$, the content of observing the pointer being in position x_2 is not visible to the observer M. While when $|\beta|^2 = 1$, the content of observing the pointer being in position x_2 is most vividly visible to the observer M.

Therefore, it seems reasonable to assume that the mental property determined by the modulus squared of the amplitude is a certain property of visibility or vividness of the mental content. For example, when $|\alpha|^2$ is close to one the part of the mental content of M observing the pointer being in position x_1 is the most vivid, while when $|\alpha|^2$ is close to zero, the part of the mental content of M observing the pointer being in position x_1 is the least vivid. In particular, when $|\alpha|^2 = |\beta|^2 = 1/2$, the part of the mental content of M observing the pointer being in position x_1 and the part of the mental content of M observing the pointer being in position x_2 have the same intermediate vividness.

On the other hand, it seems more difficult to conjecture the nature of the mental property determined by the relative phase. At the physical level, the relative phase of two braches in a superposition is a certain comparison between the two branches, and its physical effect can be detected by the interference of the two branches. Then, at the mental level, it seems that the mental property determined by the relative phase should be also a certain comparison between the parts of the mental content corrsponding to the two branches.[4] Anyway, no matter what the mental properties determined by the amplitudes and relative phases of the branches of a quanutm superposition are, they are new mental properties which do not exist in the classical

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[4] Here it is worth noting that since the mental property determined by the relative phase can hardly be imagined, it seems also possible that such mental property does not exist. Then the basic postulate about the superposition of two identical mental states, which says that an observer in a superposition of two physical states with identical mental states also has the same mental state, will be wrong, and different wave functions will not always correspond to different mental states.

world and we probably have never experienced.

To sum up, I have argued that the mental state of a quantum observer is determined by both the amplitudes and relative phases of the result branches of the superposition she is physically in, and the mental content is composed of every result. Moreover, the modulus squared of the amplitude of each result branch may determine the vividness of the part of the mental content containing the result.

5 Consciousness is fundamental

In this section, I will argue that the above results may have implications for the nature of consciousness in collapse theories. Concretely speaking, since the laws are different at the physical level and at the mental level, the mental state cannot be reduced to the physical state, and in particular, consciousness is not physically reducible or emergent but fundamental.

A direct argument is based on an analysis of the superposition principle. Consider again the observer M observing the position of a pointer which is in a position superposition:

$$(\alpha\left|1\right\rangle_P + \beta\left|2\right\rangle_P)\left|0\right\rangle_M \to \alpha\left|1\right\rangle_P\left|1\right\rangle_M + \beta\left|2\right\rangle_P\left|2\right\rangle_M\,, \tag{10}$$

where $\left|0\right\rangle_M$ is the physical state of the observer M before the observation, and $\left|1\right\rangle_M$ and $\left|2\right\rangle_M$ are the physical states of the observer M who observes the pointer being in positions x_1 and x_2, respectively. If the mental properties are reducible to the physical properties, then the corresponding evolution of the mental state of the observer M will be

$$(\alpha\left|1\right\rangle_P + \beta\left|2\right\rangle_P)\left|0\right\rangle_M\left|m_0\right\rangle_M \to \alpha\left|1\right\rangle_P\left|1\right\rangle_M\left|m_1\right\rangle_M + \beta\left|2\right\rangle_P\left|2\right\rangle_M\left|m_2\right\rangle_M\,, \tag{11}$$

where $\left|m_0\right\rangle_M$ is the mental state of the observer M before the observation, and $\left|m_1\right\rangle_M$ and $\left|m_2\right\rangle_M$ are her mental states of observing the pointer being in positions x_1 and x_2, respectively. But according to the results obtained in previous sections, the evolution of the mental state of M is

$$(\alpha\left|1\right\rangle_S + \beta\left|2\right\rangle_S)\left|0\right\rangle_M\left|m_0\right\rangle_M \to (\alpha\left|1\right\rangle_P\left|1\right\rangle_M + \beta\left|2\right\rangle_P\left|2\right\rangle_M)\left|m_{12}\right\rangle_M\,, \tag{12}$$

where $\left|m_{12}\right\rangle_M$ is the mental state of the observer M after the observation. No matter how to understand the "superposition" of two mental states in the r.h.s of (11), it is not the mental state $\left|m_{12}\right\rangle_M$ in (12) (see below for more discussion).

By this analysis, it can be seen that the laws governing the evolution of the mental state is different from the laws governing the evolution of the physical state; the evolution of the wave function satisfies the superposition principle, while the evolution of the mental state does not. In other words, the physical properties are superposed, while the mental properties are not.

The mental violation of quantum mechanics can also be seen from other aspects, e.g. measuring an unknown wave function. In quantum mechanics, an unknown quantum state or wave function cannot be measured. If the mental is reducible to the physical, then this means that an observer cannot measure an unknown measured state, such as $\alpha\left|1\right\rangle_P + \beta\left|2\right\rangle_P$. In other words, the observer cannot obtain any information about the coefficients α and β.[5] But, according to the results obtained in previous sections, an observer can obtain the information about the coefficients α and β; the mental state of the observer is determined by the values of these coefficients. The information can be used to further distinguish two non-orthogonal states with certainty (at the mental level). Note that although protective measurements can measure the wave function of a single quantum system, they need to know some information about the measured system beforehand. By comparison, a quantum observer can obtain information about an unknown wave function directly at the mental level.

Here a question appears: which mental property, if any, makes a quantum observer have the extrodinary ability to violate quantum mechanics? It is arguable that the mental property is consciousness or more specifically phenomenal consciousness. The outcome of each observation of an observer is her conscious experience, whose content contains the record of observation, such as seeing the pointer being in a position. Then, if the content contains more information than that permitted by quantum mechanics, then it seems natural to assume that the consciousness property enables the observer to obtain the information. By violating the fundamental laws of physics such as the superposition principle, consciousness is not only (physically) irreducible but also not emergent; an emergent property should also follow the fundamental laws of physics. This means that consciousness is a fundamental property.

6 Further discussion

It seems surprising that in quantum theories where the mental state of an observer is determined by the whole superposition she is physically in, such as collapse theories, consciousness (or another mental property) cannot be physically reducible or emergent but be fundamental.In this final section, I will further analyze the origin of this interesting result.

If mental properties are physically reducible or emergent, then what is

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[5] For example, the "superposition" of two mental states $\left|m_1\right\rangle_M$ and $\left|m_2\right\rangle_M$, the r.h.s of (11), which is a result of the mental being reducible to the physical, contains only information about the positions x_1 and x_2, and it does not contain information about the coefficients α and β.

the prediction of quantum mechanics for the mental state of a quantum observer? As we know, quantum mechanics requires that two non-orthogonal states cannot be distinguished with certainty. If mental properties are reducible to physical properties and thus follow the same laws as the physical properties, then this means that the mental state of a quantum observer being in a superposition like $|1\rangle_P |1\rangle_M + |2\rangle_P |2\rangle_M$ must be either $|m_1\rangle_M$ or $|m_2\rangle_M$; otherwise the observer will be able to distinguish the two non-orthogonal states $|1\rangle_P |1\rangle_M + |2\rangle_P |2\rangle_M$ and $|1\rangle_P |1\rangle_M$ or $|2\rangle_P |2\rangle_M$ with certainty. On the other hand, as I have argued before, if assuming the mental state of an observer is determined by the whole superposition she is physically in, then by symmetry of the two terms in the superposition $|1\rangle_P |1\rangle_M + |2\rangle_P |2\rangle_M$, the superposition cannot describe the observer being in the mental state $|m_1\rangle_M$ or $|m_2\rangle_M$.

Furthermore, the mental state of a quantum observer being in the superposition $|1\rangle_P |1\rangle_M + |2\rangle_P |2\rangle_M$ cannot be always $|m_1\rangle_M$ or $|m_2\rangle_M$; otherwise the observer will be also able to distinguish the two non-orthogonal states $|1\rangle_P |1\rangle_M + |2\rangle_P |2\rangle_M$ and $|1\rangle_P |1\rangle_M$ or $|2\rangle_P |2\rangle_M$ with certainty. For example, if the mental state of a quantum observer being in the superposition $|1\rangle_P |1\rangle_M + |2\rangle_P |2\rangle_M$ is always $|m_1\rangle_M$, then the observer will be able to distinguish the two non-orthogonal states $|1\rangle_P |1\rangle_M + |2\rangle_P |2\rangle_M$ and $|2\rangle_P |2\rangle_M$ with certainty. This still contradicts quantum mechanics. On the other hand, that the mental state of a quantum observer being in the superposition $|1\rangle_P |1\rangle_M + |2\rangle_P |2\rangle_M$ is sometimes $|m_1\rangle_M$ and sometimes $|m_2\rangle_M$ will be inconsistent with the assumption that the mental state of an observer is (uniquely) determined by her wave function, or in other words, it will violate the principle of psychophysical supervenience (on the wave function).

Therefore, it is the assumption that the mental state of an observer is determined by her wave function that leads to the incompatibility between quantum mechanics and the assumption that mental properties are physically reducible or emergent. By comparison, if the mental state of an observer is not determined by her wave function, but determined by another hidden variable as in Bohm's theoy or a certain definite branch of her wave function as in the many-worlds theory, then quantum mechanics and this asumption may be compatible.

The next question is: is it necessary to assume the mental state of an observer is determined by her wave function? The answer to this question is related to the measurement problem of quantum mechanics. According to the standard formulation given by Maudlin (1995), the measurement problem originates from the incompatibility of the following three claims: (1). the wave function of a physical system is a complete description of the system; (2). the wave function always evolves in accord with the Schrödinger equation; and (3). each measurement has a definite result. Correspondingly, there are three major approaches to avoiding the incompatibility and solving the measurement problem by denying one of these claims, which are Bohm's theory, Everett's theory, and collapse theories. Bohm's and Everett's theories deny the claims (1) and (3), respectively, while collapse theoriesc deny the claim (2).

In addition, and more importantly, in these theories, the measurement results are represented by different physical states, and correspondingly, the mental states of an observer are determined by these physical states. In Bohm's and Everett's theories, the measurement result is represented, and correspondingly, the mental state of an observer is determined, not by the (post-measurement) wave function, but by another definite hidden variable or one definite result branch of the wave function. This permits no existence of quanutm observers and thus avoids the issues discussed above. But in collapse theories such as the GRW theory, the measurement result is represented, and correspondingly, the mental state of an observer is determined, directly by the wave function. This will introduce quantum observers and the relevant issues discussed above.

Although it is still unknown which solution to the measurement problem is right or in the right direction, collapse theories has been widely regarded as a major option. In these theories, it is a basic assumption that the mental state of an observer is determined by her wave function. Note that in collapse theories it is not required that the wave function of a physical system is a *complete* description of the system, but it is indeed required that the wave function determines the measurement result, as well as the mental state of an observer; otherwise it would be not necessary to introduce the collapse of the wave function. For example, if the mental state of an observer being in a superposition like $|1\rangle_P |1\rangle_M + |2\rangle_P |2\rangle_M$ is already $|m_1\rangle_M$ or $|m_2\rangle_M$, then there will be no need to introduce wave-function collapse to solve the measurement problem.

There is still the last and deeper question: can consciousness or another mental property have the extrodinary ability to violate quantum mechanics? I must admit that the answer is still not available. If collapse theories is the right solution to the measurement problem, then it seems that a certain mental property such as consciousness must violate quantum mechanics. Since quantum mechanics does not consider this property as a fundamental property, it is not impossible that the property violates quantum mechanics. On the other hand, if no mental property violates quantum mechanics, then collapse theories may be not a promising solution to the measurement problem. In the final analysis, we need more empirical evidence to answer the above question. I will discuss this issue in future work.

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References

[1] Albert, D. Z. (1992). Quantum Mechanics and Experience. Cambridge, Mass.: Harvard University Press.

[2] Albert, D. Z. and B. Loewer (1996). Tails of Schrödinger's Cat. In Perspectives on Quantum Reality, eds. R. Clifton. Dordrecht: Kluwer Academic Publishers.

[3] Barrett, J. A. (1999). The Quantum Mechanics of Minds and Worlds. Oxford: Oxford University Press.

[4] Ghirardi, G. C. (2016). Collapse Theories, The Stanford Encyclopedia of Philosophy (Spring 2016 Edition), Edward N. Zalta (ed.), https://plato.stanford.edu/archives/spr2016/entries/qm-collapse/.

[5] Lewis, P. J. (1995). GRW and the Tails Problem. Topoi, 14, 23-33.

[6] Maudlin, T. (1995). Three measurement problems. Topoi 14, 7-15.