What does it feel like to be in a quantum superposition?

Shan Gao
Institute for the History of Natural Sciences,
Chinese Academy of Sciences, Beijing 100190, China.
E-mail: gaoshan@ihns.ac.cn.

December 13, 2015

Abstract

We suggest a new answer to this intriguing question and argue that the answer may have implications for the solutions to the measurement problem. The main basis of our analysis is the doctrine of psychophysical supervenience. First of all, based on this doctrine, we argue that an observer in a quantum superposition or a quantum observer has a definite conscious experience, which is neither disjunctive nor illusive. The inconsistency of this result with the bare theory is further analyzed, and it is shown that an appropriate use of the strategy of analyzing the disposition of an observer to answer a particular question also leads to the same result. Next, we argue that this new result seems to disfavor Everett's and Bohm's approaches to quantum mechanics when considering the doctrine of psychophysical supervenience. This suggests that dynamical collapse theories are in the right direction to solve the measurement problem. Thirdly, we analyze the concrete content of the conscious experience of a quantum observer. It is argued that the mental content of a quantum observer is related to both the amplitude and relative phase of each branch of the superposition she is physically in, and it is composed of the mental content corresponding to every branch of the superposition. In addition, we argue that when assuming the modulus squared of the amplitude of each branch determines the vividness of the mental content corresponding to the branch, the structured tails problem of dynamical collapse theories can be solved.

1 Introduction

It has been realized that the measurement problem in quantum mechanics is essentially the determinate-experience problem in the final analysis (Barrett, 1999). The problem is to explain how the linear dynamics can be compatible with the existence of our definite experience. This means that in order to finally solve the measurement problem it is necessary to analyze the observer who is physically in a superposition of brain states with definite conscious experiences such as definite measurement records. Indeed, such quantum observers exist in the main realistic solutions to the measurement problem, including Bohm's theory, Everett's theory, and even the dynamical collapse theories.[1] Then, what does it feel like to be a quantum observer? In his book *Quantum Mechanics and Experience*, David Albert first asked this intriguing question and also suggested an interesting answer, the bare theory (Albert, 1992, p.124). The theory was analyzed by several other authors later (Barrett, 1994, 1998a, 1998b, 1999; Weinstein, 1996; Bub, Clifton and Monton, 1998; Dickson, 1998; Magnus, 2004). Certainly, the above realistic alternatives to quantum mechanics also give their respective answers. In this paper, we will suggest a new answer to this question. Moreover, we will argue that the suggested answer, if it is true, will have implications for the solutions to the measurement problem.

This paper is organized as follows. In Section 2, we argue that a quantum observer, like a classical observer, also has a (normal) definite conscious experience. Two arguments are given. The first argument is based on the doctrine of psychophysical supervenience, and the second argument is based on Albert's strategy of analyzing the disposition of an observer to answer a particular question. In Section 3, we analyze the bare theory, which seems to raise a serious objection to our arguments. According to the theory, a quantum observer has a definite conscious experience, but the experience is not normal but disjunctive and also illusive. It is argued that the bare theory is based on a questionable analysis of how a quantum observer answers a particular question, and it does not pose a threat to our arguments. In Section 4, we discuss possible implications of the above analysis for the solutions to the measurement problem. It is argued that Everett's and Bohm's approaches to quantum mechanics are disfavored when considering the doctrine of psychophysical supervenience. It is also pointed out that although dynamical collapse theories are favored, they are plagued by the structured tails problem. In order to solve this serious problem, we further analyze the concrete content of the conscious experience of a quantum observer in Section 5. We argue that the mental content of a quantum observer is related to both the amplitude and relative phase of each branch of the superposition she is physically in, and it is composed of the mental content corresponding to every branch of the superposition. In addition, we argue that when assuming the modulus squared of the amplitude of each branch determines the vividness of the mental content corresponding to the branch, the structured tails problem can be solved. Conclusions are given in the last section.

[1]Note that in the dynamical collapse theories there are also quantum observers due to the imperfectness of wavefunction collapse, which leads to the well-known tails problem.

2 A quantum observer has a definite conscious experience

Suppose there is an ideal x-spin observer M who measures the x-spin of a spin-l/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 the measurement S will be still in the x-spin up state, and M will physically record the x-spin up result and mentally have the corresponding conscious experience whose content is that the measurement result is 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 mentally have the corresponding conscious experience whose content is that the measurement result is 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

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

then by the linear dynamics the physical state of M and S after M's x-spin measurement will be

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

Now the question is: What conscious experience does M have when she is physically in this superposition state? In order to answer this question, we need to resort to certain fundamental assumptions about the relationship between the physical state and the mental state. Here we resort to the doctrine of psychophysical supervenience, which says two observers cannot differ mentally without also differing physically, or in other words, two identical brain states or processes correspond to the same mental state. Note that the existing neuroscience experiments support this doctrine, and no evidence has been found to contradict it. Since a mental state not only has its mental content but also has some other properties such as the vividness of the content etc, the doctrine of psychophysical supervenience further means that each of these properties also supervenes on certain aspect or part of the physical state or process underlying the mental state. In other words, if two different physical states or processes have some identical parts, then the two corresponding mental states will have the same mental properties determined by these parts.

It can be seen that the mental states of M corresponding to the physical states $|up\rangle_M$ and $|down\rangle_M$ only differ in their content, and their other properties are the same. Then the parts of the two physical states on which these mental properties supervene are also the same.[2] This means that these parts will be a common factor which can be picked out from the above superposition of the two physical states, (4). Then by the psychophysical supervenience the mental state corresponding to the superposition will also have these mental properties. In the quantum context, an important and widely-discussed example of such mental properties is whether or not a mental state has a definite conscious experience. When considering the measurement of an observer, this mental property is whether or not the observer is consciously aware of a definite record after the measurement. This property is independent of what specific record the observer obtains.[3] Then by the above analysis, the mental state corresponding to the above superposition (4) also has this mental property, which means that the quantum observer M in the superposition is consciously aware of a definite record after the measurement.

A weaker form of this result can be obtained by a different reasoning (Albert, 1992; Barrett, 1999). Here is the argument. In the above example, suppose that M has the disposition to answer the question "Did you get a definite result to your x-spin measurement?" with "Yes" if she recorded x-spin up (if M + S ended up in the state $|up\rangle_S |up\rangle_M$) and with "Yes" if she recorded x-spin down (if M + S ended up in the state $|down\rangle_S |down\rangle_M$). Then if M + S is in a superposition of these two states, such as (4), then it follows from the linearity of the dynamics that M will answer "Yes" to the same question; that is, M will report that she got a definite x-spin record.[4] This result can also be obtained by an argument using reduction to absurdity (see also Barrett, 1998; Magnus, 2004). Assuming that if M + S is in a superposition of $|up\rangle_S |up\rangle_M$ and $|down\rangle_S |down\rangle_M$, M will report that she did not get a definite x-spin record. Then since an appropriate superposition of two such superpositions may also be the state $|up\rangle_S |up\rangle_M$ or $|down\rangle_S |down\rangle_M$, M will also report that she did not get a definite x-spin record when she determinately recorded x-spin up or x-spin down by the linearity of the dynamics. This leads to a contradiction.

[2]Here it is implicitly assumed that for the same observer each of these mental properties supervenes on one and only part of the whole physical state underlying the mental state.

[3]Moreover, the observer can also determine whether she has this mental property by introspection, and the determination may not depend on the specific record she obtains either.

[4]In our view, the linearity of the dynamics seems not necessary for the argument. M's report can be represented by a physical state. And the physical state corresponding to her "Yes" report is a common factor which can be picked out from the superposition (4). Thus M's report is still "Yes" when she is in the superposition.

This argument is not based on the doctrine of psychophysical supervenience, and its conclusion is weaker than the result we obtained based on the doctrine. However, when assuming that a qualified observer can correctly report her mental content, this result will be equivalent to the result we obtained. Therefore, along two different lines of reasoning, we can argue that a quantum observer, who is physically in a superposition state like (4), also has a definite conscious experience.

3 The either/or puzzle

Before moving on to analyzing what definite conscious experience a quantum observer has, we need to pause to first solve a puzzle. The puzzle concerns a different question one can ask in the above weaker argument (Albert, 1992; Barrett, 1999).

Suppose that M is asked not with the question "Did you get a definite result to your x-spin measurement?", but with the question "Did you get some definite result to your x-spin measurement, either x-spin up or x-spin down?" Then the same observer M will also have the disposition to answer this question with "Yes" if she recorded x-spin up (if M + S ended up in the state $|up\rangle_S |up\rangle_M$) and with "Yes" if she recorded x-spin down (if M + S ended up in the state $|down\rangle_S |down\rangle_M$). Then if M + S is in a superposition of these two states, (4), it follows from a similar analysis that M will also answer "Yes" to the question; that is, M will report that she got a definite x-spin result, either x-spin up or x-spin down. However, M in fact fails to have either definite record when she is physically in the superposition (4). We call this puzzle the either/or puzzle. It thus seems that the previous assumption that a qualified observer can correctly report her mental content is not always true in the quantum context. This also raises the doubt about the correctness of M's report that she got a definite x-spin result when she is physically in the superposition (4).

According to the well-known solution to this puzzle (Albert, 1992; Barrett, 1999), M will indeed report that she got a definite x-spin result, either x-spin up or x-spin down, when she is physically in the superposition (4), but the report is false. This means that even a qualified observer cannot know what she is currently experiencing and what she had experienced, and she will be fundamentally mistaken concerning the basic nature of her conscious experience. The resulting theory is called the bare theory (Albert, 1992), which has many serious problems such as the empirical incoherence problem (which is that if the theory were true, we would have no empirical evidence to confirm that it is true) (Barrett, 1996, 1999; Dickson, 1998; Magnus, 2004). However, although the bare theory is generally rejected due to these serious problems, it seems that the origin of the either/or puzzle has not been deeply analyzed.

Let us compare the two questions "Did you get a *definite* result to your x-spin measurement?" and "Did you get some definite result to your x-spin measurement, *either x-spin up or x-spin down*?". The difference lies in that the second question also concerns the specific result of measurement, while the first question does not. In order to answer the second question, the observer M must first know the content of her immediate conscious experience or memory about the measurement result. Moreover, only after an either/or logical analysis can she give an answer to the question. (In contrast, M needs not know her specific mental content to answer the first question.) Therefore, the fact that M fails to have either definite record will not result in the mental illusion assumed by the bare theory; rather, it will result in the negative answer of M to the second question, and this report is true. Concretely speaking, since the mental states corresponding to the physical states $|up\rangle_M$ and $|down\rangle_M$ differ in their mental content, the observer M being in the superposition (4) will have a conscious experience different from the experience of M being in each branch of the superposition by the symmetry of the two branches. In other words, the result that M is consciously aware of is neither x-spin up nor x-spin down when she is physically in the superposition (4). Thus M will, in fact, answer "No", not "Yes", to the second question, "Did you get some definite result to your x-spin measurement, *either x-spin up or x-spin down*?" (if she is a qualified and honest observer). [5]

It is worth noting that even though the observer M being in the superposition (4)) has a (definite) disjunctive conscious experience, such as "I am consciously aware of a result, either x-spin up or x-spin down" (Barrett, 1999), the conscious experience is also different from the experience of M being in each branch of the superposition. If the question "Did you get some definite result to your x-spin measurement, either x-spin up or x-spin down?" means that "Are you consciously aware of a x-spin up result or a x-spin down result to your x-spin measurement?", then M's answer to the question will be still "No", not "Yes".

This solution to the either/or puzzle makes the invalidity of the bare theory more obvious. Moreover, the solution also helps clear the doubt about the validity of the previous assumption that a qualified observer can correctly report her mental content in the quantum context, and in particular, the correctness of M's report that she got a definite x-spin result when she is physically in the superposition (4).

[5]Another way to understanding this result is to notice that since the mental states corresponding to the physical states $|up\rangle_M$ and $|down\rangle_M$ are incompatible in their mental content, there is no common part of the two physical states on which the mental content of the observer M being in a superposition of them can supervene. As a result, even though the observer M being in each branch of the superposition answers "Yes" to a question concerning her mental content, she cannot give the same answer to the question when she is in the superposition.

4 Implications for solving the measurement problem

According to the above analysis, when an ideal x-spin observer measures the x-spin of a spin-1/2 system being in a superposition of x-spin up and x-spin down, she will be consciously aware of a definite record, which is neither x-spin up nor x-spin down. This new result, if it is valid, will have implications for solving the measurement problem.

4.1 Everett's approach

Let us first analyze Everett's approach to quantum mechanics. This approach claims that after the above quantum measurement there will be two observers, each of who is consciously aware of a definite record, either x-spin up or x-spin down.

There are in general two ways of understanding the notion of multiplicity in Everett's approach. One is the strong form which claims that there are two *physical* observers (in material content) after the quantum measurement (e.g. DeWitt and Graham, 1973). The above new result, which is based on the assumption that there is still one *physical* observer after the quantum measurement, has no implications for this view, which is consistent with the doctrine of psychophysical supervenience. As is well known, however, this view has serious problems such as violation of mass-energy conservation and inconsistency with the dynamical equations (Albert and Loewer, 1988). The problem of inconsistency can also be seen as follows. The existence of many worlds is only relative to decoherent observers, not relative to non-decoherent observers, who can measure the whole superposition corresponding to the many worlds (e.g. by protective measurements) and confirm that there is no increase in the total mass-energy and number of particles.

The other way of understanding the notion of multiplicity is the weak form which claims that there is one *physical* observer (in material content), but there are two *mental* observers or two mental states of the same physical observer after the quantum measurement. Wallace's (2012) latest formulation of Everett's approach is arguably this view in nature (see also Kent, 2010).[6] Our new result, which is also based on the assumption that there is still one *physical* observer after the quantum measurement, will have implications for this view.

The difference between the prediction of the weak form of Everett's approach and our result is obvious. Let us see where the difference originates from. In order to derive the multiplicity prediction of Everett's approach,

[6]Note that in Wallace's formulation it is claimed that there are also two emergent physical observers, but their existence is only in the sense of branch structure (i.e. the structure of certain parts of a whole physical state), not in the sense of material content.

the mental state of a conscious observer cannot always supervene on her whole physical state. For each of the physical states $|up\rangle_M$ and $|down\rangle_M$, the mental state directly supervenes on the whole physical state. But for a superposition of these two physical states such as (4), the mental state does not supervene on the whole physical state; rather, the mental state supervenes only on a part of the whole physical state, such as one of the two terms in the superposition (4), and as a result, a physical observer has two distinct mental states at the same time. This obviously contradicts the common assumption of psychophysical supervenience, which states that the mental state of a conscious observer supervenes on her (whole) physical state. Note that a whole physical state is independent, while any two parts of the state are not independent; once one part is selected, the other part will be also fixed. But a mental state is usually assumed to be autonomous. Thus it is arguably that a mental state supervenes on a whole physical state, not on any part of the state.

Although one may still object that this common assumption may be invalid in the quantum domain, one must explain why the assumption applies to the physical states $|up\rangle_M$ and $|down\rangle_M$, but not to any superposition of them. It seems that the only difference one can think is that being in the superposition the physical observer has no definite mental state which contains a definite conscious experience about the measurement result, while being in each branch of the superposition, $|up\rangle_M$ or $|down\rangle_M$, she has a definite mental state which contains a definite conscious experience about the measurement result. According to our previous analysis, however, this difference in fact does not exist; a physical observer being in the superposition also has a definite mental state which contains a definite conscious experience about the measurement result. Note that these objections also apply to the single-mind theory and many-minds theory.[7]

Finally, we give a brief comment on the relationship between Everett's approach and decoherence. It is usually thought that the appearance or emergence of two observers after a quantum measurement with two possible results is caused by decoherence. However, even if this claim is true for the strong form of Everett's approach, it cannot be true for the weak form of Everett's approach. The reason is that the generation of a superposed state of a physical observer (e.g. a superposition of two physical states $|up\rangle_M$ and $|down\rangle_M$), as well as the psychophysical supervenience, have nothing to do with decoherence. In this sense, the weak form of Everett's approach is more like a many-minds theory than a many-worlds theory. Note again that in the weak form of Everett's approach the observer still has a whole physical state after a quantum measurement. In our opinion, it is just the fuzzy

[7]It seems that these objections will be more serious for Wallace's formulation of Everett's approach, since in this formulation, which is arguably a weak form of Everett's approach too, there are no definite parts of the whole physical state on which the mental states can supervene.

border between a many-minds theory and a many-worlds theory that causes much confusion in understanding Everett's approach to quantum mechanics (see also Kent, 2010).

4.2 Bohm's approach

Let us now consider Bohm's approach or the hidden-variables approach to quantum mechanics. As to Bohm's approach, an analysis of the psychophysical supervenience is also relevant and necessary (Brown, 1996). In this approach, there are two possible forms of psychophysical supervenience. One is that the mental state supervenes on both the wave function and the additional variables such as positions of Bohmian particles. The other is that the mental state supervenes only on the additional variables such as positions of Bohmian particles.

If assuming the first form of psychophysical supervenience, then our new result will have implications for Bohm's approach. On the wave function part, the mental state of a quantum observer being in a superposition such as (4) is also definite, and the mental content does not correspond to either branch of the superposition. Then, even although the mental state of the observer also contains the content corresponding to the branch occupied by the Bohmian particles, the whole content does not correspond to either branch of the superposition. Therefore, in this case Bohm's approach cannot solve the measurement problem, and is not consistent with the predictions of standard quantum mechanics either.

It is usually thought that the mental state of a quantum observer being in a superposition supervenes only on the branch of the superposition occupied by the Bohmian particles. Indeed, Bohm initially assumed this form of psychophysical supervenience. He said: "the packet entered by the apparatus [hidden] variable... determines the actual result of the measurement, which the observer will obtain when she looks at the apparatus." (Bohm, 1952, p.182). Brown and Wallace (2005) called this assumption Bohm's result assumption, and they have presented convincing arguments against it (see also Lewis, 2007). In our view, the main problem with this assumption is that the occupied branch and other empty branches have the same ontological status and ability to be supervened by the mental state. Moreover, although it is imaginable that the Bohmian particles may have influences on the occupied branch, e.g. disabling it from being supervened by the mental state, it is hardly imaginable that the Bohmian particles have influences on all other empty branches, e.g. disabling them from being supervened by the mental state.

On the other hand, if assuming the second form of psychophysical supervenience, namely assuming the mental state supervenes only on the positions of Bohmian particles, then our new result will have no implications for Bohm's approach, and it seems that the above inconsistency problem can also be avoided. Indeed, most Bohmians today seem to support this assumption, though they often did not state it explicitly (see, e.g. Maudlin, 1995). However, it has been argued that this assumption also leads to a serious problem of allowing superluminal signaling (Brown and Wallace 2005; Lewis, 2007). In our view, this problem is not as deadly as the inconsistency problem, since such superluminal signaling may exist in principle, and its existence is not inconsistent with existing experience either (Gao, 2004).

The problem with this assumption is still the inconsistency problem. Here is an argument. Consider again a quantum observer being in the superposition (4). In Bohm's approach, the Bohmian particles of the observer reside in one branch of the superposition after the measurement, which indicates that the observer obtains the result corresponding to the branch. For example, when the Bohmian particles of the observer reside in the branch $|up\rangle_M$ after the measurement, the observer obtains the x-spin up result; while when the Bohmian particles of the observer reside in the branch $|down\rangle_M$ after the measurement, the observer obtains the x-spin down result. Now suppose these two post-measurement situations appear in two somewhat different experiments so that the Bohmian particles of the two observers are located in the same positions. Then if assuming the second form of psychophysical supervenience, namely assuming the mental state supervenes only on the positions of Bohmian particles, then these two post-measurement situations will represent the same measurement result. But this is not the case; in the first situation the observer obtains the x-spin up result, while in the second situation she obtains the x-spin down result.[8]

This analysis also raises a further doubt about the whole strategy of Bohm's approach to solving the measurement problem. Why add hidden variables such as positions of Bohmian particles to quantum mechanics? It has been thought that adding these variables which have definite values at every instant is enough to ensure the definiteness of measurement results and further solve the measurement problem. However, if the mental state cannot supervene on these additional variables, then even though these variables have definite values at every instant, they are unable to account for our definite experience and thus do not help solve the measurement problem.

4.3 Dynamical collapse theories

We have argued that when considering the mental content of a quantum observer being in a superposition such as (4), it seems that Everett's and Bohm's approaches to quantum mechanics are not promising solutions to the measurement problem. If a quantum observer being in a post-measurement

[8] This point was also emphasized by Barrett (1999, p.123). He said: "the content of a measurement record in Bohm's theory is determined by the position of something *relative* to the wave function - that is, a different wave function and the same position might produce a different record."

superposition like (4) indeed is consciously aware of a definite result, which is not one of the possible results of the measurement, then the final state of the observer after the measurement cannot be such a superposition. This means that the linear quantum dynamics will be violated during the measurement. Thus it seems that dynamical collapse theories are in the right direction to solve the measurement problem.

However, it has been known that dynamical collapse theories are plagued by the tails problem (Albert and Loewer, 1996). In particular, the structured tails problem has not been solved in a satisfactory way (see McQueen, 2015 and references therein). The problem is essentially that dynamical collapse theories such as the GRW theory predicts that the post-measurement state is still a superposition of different outcome branches with similar structure (although the modulus squared of the coefficient of one branch is close to one), and they need to explain why high modulus-squared values are macro-existence determiners (McQueen, 2015). In our view, the key to solving the structured tails problem is not to analyze the connection between high modulus-squared values and macro-existence, but to analyze the connection between these values and our experience of the macroscopic world. This brings us again to the question of what it feels like to be in a quantum superposition.

5 What does a quantum observer observe?

Consider a quantum observer M being in the following superposition:

$$\alpha \left|1\right\rangle_P \left|1\right\rangle_M + \beta \left|2\right\rangle_P \left|2\right\rangle_M , \tag{5}$$

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 (consciously) 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 our previous analysis, a quantum observer, who is physically in a superposition state like (5), also has a definite conscious experience. The question now is: What does M observe when she is physically in the above superposition state?

First of all, it can be seen that the mental content of the observer M is related to the modulus squared of 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 $\alpha = \beta = 1/\sqrt{2}$, by the symmetry of the two branches the mental content of M will be neither the content of observing the pointer being in position x_1 nor the content of observing the pointer being in position x_2.

Next, it can be argued that the mental content of the observer M is also related to the phase of each branch of the superposition she is physically in. Assume this is not the case. Then when $\alpha = -\beta = 1/\sqrt{2}$ and when $\alpha = \beta = 1/\sqrt{2}$, the mental content of M will be the same, which is neither the content of observing the pointer being in position x_1 nor the content of observing the pointer being in position x_2. Then, by an analysis similar to that given in Section 2, when M is in a superposition of these two physical states, her mental content is still the same. However, since the superposition of these two states is $|1\rangle_P |1\rangle_M$, the observer M being in this superposition will observe the pointer being only in position x_1. This leads to a contradiction. Note that the mental content of M is only related to the relative phase of each branch of the superposition she is physically in, since an overall phase has no physical meaning, and two physical states with only a difference of overall phase are in fact the same physical state.

Thirdly, it might be argued that the mental content of the observer M 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. It is natural to assume when the physical state changes continuously the corresponding mental state also changes continuously. This means that when the amplitude or phase of each branch of the superposition (5) changes continuously, the mental content of the observer M also changes continuously. When $|\alpha|^2$=1, M will observe the pointer being in position x_1. While when $|\alpha|^2$=0, M will not observe the pointer being in position x_1. Then under this continuity assumption, when $|\alpha|^2$ is close to one the mental content of M will still contain the content of observing the pointer being in position x_1. Moreover, it seems also natural to assume for other values of $|\alpha|^2$ which are not zero, the mental content of M will still contain the content of observing the pointer being in position x_1. Similarly, for all values of $|\beta|^2$ which are not zero the mental content of M will also contain the content of observing the pointer being in position x_2. However, the mental content of the observer M does not contain the content of observing the pointer being in another position x_3 which is different from x_1 and x_2, since the amplitude of the corresponding term $|3\rangle_P |3\rangle_M$ is exactly zero. To sum up, it is arguably that the mental content of the observer M 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, which are also the only two parts of the whole mental content of M.

In order to know how the partial contents constitute the whole mental content of a quantum observer being in a superposition, we need to further analyze how the amplitude and phase of each branch of the superposition determine the mental content. This is a difficult task. And we can only give a few speculations here. It seems reasonable to assume that the mental property determined by the modulus squared of the amplitude is a certain property of vividness of the conscious experience. For example, when $|\alpha|^2$

is close to one the conscious experience of M observing the pointer being in position x_1 is the most vivid, while when $|\alpha|^2$ is close to zero, the conscious experience of M observing the pointer being in position x_1 is the least vivid. In particular, when $|\alpha|^2 = |\beta|^2 = 1/2$, the conscious experience of M observing the pointer being in position x_1 and the conscious experience of M observing the pointer being in position x_2 have the same intermediate vividness. However, it is more difficult to conjecture the nature of the mental property determined by the relative phase. It is most probably a new property which we don't know and have not experienced either.

The above analysis of the mental content of a quantum observer, though it is speculative, may help solve the structured tails problem of dynamical collapse theories. In particular, if assuming the modulus squared of the amplitude of each branch indeed determines the vividness of the mental content corresponding to the branch, then the structured tails problem can be readily solved. Under this assumption, when the modulus squared of the amplitude of a branch is close to zero, the mental content corresponding to the branch will be the least vivid. It is conceivable that below a certain threshold of vividness an ordinary observer or even an ideal observer will not be consciously aware of the corresponding mental content. Then even though in dynamical collapse theories the post-measurement state of an observer is still a superposition of different outcome branches with similar structure, the observer can only be consciously aware of the mental content corresponding to the branch with very high amplitude, and the branches with very low amplitude will have no corresponding mental content appearing in the whole mental content of the observer. This will solve the structured tails problem of dynamical collapse theories.

6 Conclusions

In this paper, we suggest a new answer to the question of what it feels like to be a quantum observer, and argue that the answer may have implications for the solutions to the measurement problem. Our main strategy is to apply the doctrine of psychophysical supervenience in our analysis. Based on this doctrine, we first argue that a quantum observer has a definite conscious experience, which is neither disjunctive nor illusive. The inconsistency of this result with the bare theory is resolved, and it is shown that that an appropriate use of the strategy of analyzing the disposition of an observer to answer a particular question also leads to the same result. We then analyze possible implications of this new result for the solutions to the measurement problem. It is argued that Everett's and Bohm's approaches to quantum mechanics are disfavored when considering the doctrine of psychophysical supervenience. This suggests that dynamical collapse theories are in the right direction to solve the measurement problem. In order to solve the structured tails problem of these theories, we further analyze the concrete content of the conscious experience of a quantum observer. It is argued that the mental content of a quantum observer is related to both the amplitude and relative phase of each branch of the superposition she is physically in, and it is composed of the mental content corresponding to every branch of the superposition. In addition, we argue that when assuming the modulus squared of the amplitude of each branch determines the vividness of the mental content corresponding to the branch, the structured tails problem can be solved.

Acknowledgments

Most parts of this paper were written when I taught *The Philosophy of Quantum Mechanics* to the postgraduates at Chinese Academy University. I thank the International Conference Center of the University for providing comfortable accommodation. This work is partly supported by the Top Priorities Program of the Institute for the History of Natural Sciences, Chinese Academy of Sciences under Grant No. Y45001209G.

References

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

[2] Albert, D. Z. and B. Loewer. (1988). Interpreting the Many Worlds Interpretation, Synthese, 77, 195-213.

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

[4] Bohm, D. (1952). A suggested interpretation of quantum theory in terms of "hidden" variables, I and II. Phys. Rev. 85, 166-193.

[5] Brown, H. R. (1996). Mindful of quantum possibilities. British Journal for the Philosophy of Science, 47, 189-200.

[6] Brown, H. R. and D. Wallace (2005). Solving the measurement problem: de Broglie-Bohm loses out to Everett, Found. Phys. 35, 517-540.

[7] Barrett, J. A. (1994). The Suggestive Properties of the Bare Theory of Quantum Mechanics, Erkenntnis 41, 233-252.

[8] Barrett, J. A. (1998a). On the nature of experience in the Bare Theory, Synthese 113, 347-55.

[9] Barrett, J. A. (1998b). The bare theory and how to fix it, in D. Dieks and P. E. Vermaas (eds.), The Modal Interpretation of Quantum Mechanics. New York: Kluwer Academic Publishers, pp. 319-36.

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

[11] Bub, J., R. Clifton, and B. Monton (1998). The bare theory has no clothes, in R.A. Healey and G. Hellman (eds.), Minnesota Studies in Philosophy of Science, XVII, Minneapolis: University of Minnesota Press, pp. 32-51.

[12] DeWitt, B. S. and N. Graham (eds.). (1973). The Many-Worlds Interpretation of Quantum Mechanics. Princeton: Princeton University Press.

[13] Dickson, M. (1998). Quantum Chance and Non-locality. Cambridge: Cambridge University Press.

[14] Gao, S. (2004). Quantum collapse, consciousness and superluminal communication, Found. Phys. Lett, 17, 167-182.

[15] Kent, A. (2010). One World versus Many: The Inadequacy of Everettian Accounts of Evolution, Probability, and Scientific Confirmation. In S. Saunders, J. A. Barrett, A. Kent, and D. Wallace (eds.). Many Worlds? Everett, Quantum Theory, and Reality. Oxford: Oxford University Press. pp.307-354.

[16] Lewis, P. J. (2007). How Bohm's Theory Solves the Measurement Problem. Philosophy of Science 74, 749-760.

[17] Magnus, P. D. (2004). The price of insisting that quantum mechanics is complete. British Journal for the Philosophy of Science, 55, 257-267.

[18] Maudlin, T. (1995). Why Bohm's theory solves the measurement problem. Philosophy of Science 62, 479-483.

[19] McQueen, K. J. (2015). Four tails problems for dynamical collapse theories. Studies in History and Philosophy of Modern Physics 49, 10-18.

[20] Wallace, D. (2012). The Emergent Multiverse: Quantum Theory according to the Everett Interpretation. Oxford: Oxford University Press.

[21] Weinstein, S. (1996). Undermined, Synthese 106, 241-251.