What are quantum theorists doing at a conference on consciousness?\textsuperscript{1}

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February, 1996

Abstract

The reason why orthodox quantum theory necessarily invokes consciousness is explained. Several procedures whereby the Born probability rule can be introduced are discussed, and reasons are given for preferring one in which consciousness selects a unique realised world. Consciousness is something outside of the laws of physics (quantum mechanics), but it has a real effect upon the experienced world. Finally, orthodox quantum theory is shown to require that consciousness acts non-locally.

A possible answer to the question in the title of this talk would be to say that we can explain consciousness. That would be false; we have no more idea how to explain consciousness than anyone else, which means we have NO idea! In fact the whole idea of trying to explain consciousness is probably a mistake; consciousness just is.

The proper answer to the question is that we cannot understand quantum theory without invoking consciousness.\textsuperscript{3}

Quantum theory is a wonderful elegant theory, which, at least in principle, allows us to calculate the properties of all physical (and chemical) systems. It gives correct results for the probabilities of particular results of an enormous range of experiments. It is accurate and universal, and no violations of its predictions are known, even where those predictions are very counter-intuitive.

BUT, if quantum theory really applies to all systems, then, except in very special circumstances, there can never be any observations, i.e., there can be no events for which the above statistical predictions could apply.

This fact is so important, and so simple, that we shall discuss an example. We imagine that there is a system, the one to be “measured”, which is in a state that I describe as $|+\rangle$. (There is no need to worry what this means or why I use such a funny notation).

This system in measured with an apparatus $A$, and I suppose that after the measurement the combined system can be described by $|+, A^+\rangle$. What this means is that the $+$ reading on the apparatus corresponds to the system being in the state $+$. Generally the apparatus is not isolated but in interaction with an environment (air, microwave background, black-holes, strings, etc.). Call all this $E$, then the full state is $|+, A^+, E^+\rangle$. Of course this will in general be changing with time, but I do not need to indicate this explicitly.

Next, I suppose that Melinda looks at the apparatus. This puts her brain, denoted by $Me$, into a certain state. Hence the state of the relevant system is now

$$|+, A^+, E^+, Me^+\rangle.$$  \textsuperscript{(1)}

\textsuperscript{1} Text of talk to be given at the Tucson II conference, Towards a Science of Consciousness, 1996
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\textsuperscript{3} The interpretation problem of quantum theory and the hard problem of consciousness also share the property of attracting articles that claim to provide a solution but in fact do not address the problem.
Everything up to here is perfectly straightforward. Assuming that I knew the physical structure of the apparatus (not too difficult to imagine), of the environment (a bit harder) and of Melinda’s brain (harder still), then the evolution to this final state could be calculated from the Schrödinger equation.

Notice that it is totally irrelevant to the discussion what is the precise nature of the physical brain; we need make no assumptions whatever about that, except that the brain is a physical thing and is therefore described by the laws of quantum theory.

Now we need to introduce the bit that we none of us know anything about. Presumably the $Me^+$ state of Melinda’s brain corresponds to some sort of “pattern” which her consciousness, knowing something about the apparatus $A$, interprets as meaning that the system was in the state $+$. To be concrete, suppose the pattern is as given in fig. 1.

We can then repeat the above discussion with some other state of the system. Let us call this state $|-\rangle$. In an obvious generalisation of the notation used above, the state after measurement will now be

$$|−, A^−, E^−, Me^− >. \quad (2)$$

Again there will be some pattern in Melinda’s brain which her consciousness recognises as meaning that the system was in the state $−$. Suppose this time the pattern is as in fig. 2.

At this stage we do not have anything that is different from classical physics. The calculation yields a particular result which is interpreted by consciousness. These however are the “special circumstances” referred to above, where there is no measurement problem.

The problem arises because it is possible, and indeed in some cases very easy, to prepare a state which is not $+$ or $−$, but is a “bit of each”. We write this as $a|+ > + b|− >$, where the relative magnitudes of $a$ and $b$ tell us something about how much of $+$ compared to $−$ the state contains. In practice most states that are observed will have this form. (To prevent any possible misunderstanding here it is important to emphasise that this new state is not just a way of saying that the state might be $+$ or it might be $−$, and that we do not know which. Quantum theory allows us to discuss this situation - the state is then called a mixed state - but it is not what we have here.)

What happens when we measure this new state using the same apparatus as before? Here is another piece of quantum magic. Given the results of the previous calculations, it is a trivial matter to calculate what happens. In fact the final state becomes

$$a|+, A^+, E^+, Me^+ > + b|−, A^−, E^−, Me^− >. \quad (3)$$

We do not get one pattern, or the other, but something that is a bit of one and a bit of the other. There is nothing obviously remarkable about that; we started with the system in a state which we wrote as a “sum” of system states, and we finish with a similar type of sum of observed states.

Now come the surprises.

1. It is a simple matter of fact that Melinda will experience either the $+$ state or the $−$ state. As far as her experience is concerned the state (3) will be exactly as if it were either that in (1) or that in (2).

To be careful here, I should say that this is what Melinda will tell us. In order to be sure (see below) we can check by doing the observation ourselves. Then I will be aware of either the pattern of fig 1 or the pattern of figure 2 - certainly not the “sum” of the two patterns as in fig. 3.

Notice that this one result of which I am aware exists in Consciousness, but not in “physics”, i.e., no particular result is present in the state of the physical world as it is calculated according to quantum theory. If this is “dualism” then I am happy to be called a dualist.

2. The above fact follows from orthodox quantum theory - in the sense that will be made clear immediately. Because I sometimes read statements that seem to deny this, and because it is important to be precise about what is meant, and because, if we think about it, it is rather amazing, I shall derive it.

To do this I suppose that Melinda had agreed to write a 0 on a piece of paper as soon as she knew whether the system was in the state $+$ or the state $−$. Note that she does not write down what it is, only that she knows what it is. Clearly, in both the cases where the system was in the state $+$ or $−$, as soon as she had looked at the apparatus, then she would have written the 0. It then follows trivially from standard quantum theory that in the case where the state was the sum of the two, she would again write down the 0.
Thus, she would tell the world that she had become aware of either the pattern in fig. 1, or the pattern in figure 2. Every physical action she took would convey this message. I think this means that she would indeed have become aware of one result, as indeed we know happens in practice. Otherwise she would consistently be telling the world, and herself, a lie.

This seems to imply that orthodox quantum theory has told us something about how consciousness actually works. Of course it cannot do this. We have inserted an assumption of consistency. All Melinda’s physical actions, as long as they are governed by quantum theory will imply that she knows a unique result. The assumption is that this actually means that she does know such a result. One could imagine (just about) that, on the contrary, she was not aware of any result, but that nevertheless she put the 0 on the paper, and in all other ways behaved as though she did.

It is worth noting that we cannot run this argument with a computer (try it). It works because Melinda is conscious and it therefore makes sense to talk about “knowing”. Computers, on the other hand do not know anything, and we would not have any way of giving the essential instruction to write a 0 as soon as the result is known.

3. Here is something that does not follow from the simple evolution equation of quantum theory, i.e., the Schrödinger equation, which is all we have used so far. In a large set of identical runs of the above experiment the number of times Melinda would see + and − would be in the ratio $|a|^2/|b|^2$. This is a “rule” which is sort of added to quantum theory. It is called the Born rule (after Max Born who first proposed it), and it has been confirmed repeatably in myriads of experiments.

So, where is the problem, and what has all this got to do with consciousness?

The complete description of the “physics” in orthodox quantum theory is the state displayed above, which contains both terms, i.e. both “results”. The unique result of which I am aware does not exist in physics - but only in consciousness. The Born rule does not have anything to say about physics - it says something about consciousness.

I must qualify the above by emphasising the fact that I am speaking of orthodox quantum theory. I could add something to physics (e.g. the Bohm hidden variable model) or I could change it (e.g. the explicit collapse models of GRW/Pearle etc), so that the result would be in the physics. Even then the properties of consciousness would appear, but all that is another story which we shall not follow here.

Naive Many-Minds Interpretation

To continue, we note that the simplest possibility for what is happening would be that after the measurement there are two “Melinda’s”, one of which has one experience, and one of which has the other. We need have no concern that this does not appear to Melinda to be what is happening, because it is guaranteed by quantum theory that each “Melinda” will be unaware of the existence of the other, and will indeed have no possibility of knowing about the other (this is true for all practicable purposes - if she were sufficiently clever she could perhaps devise means of checking whether the other Melinda really exists). What we have here is the “naive” many-worlds interpretation of quantum theory; it is better called the “many-views” or “many minds” interpretation [1...4] because the physical world, described by the quantum state, e.g., as displayed above in our simple example (eq. 3), is always ONE thing.

Two points should be noted here. First, the experienced world is precisely that, the world as experienced. It is not identical to the physical world. When we “measure” something, we experience a particular result, but, in general, that result does not refer to anything that was there before our experience of it, or even after the experience; it exists only in consciousness. Secondly, all this has been achieved with nothing beyond orthodox quantum theory.

However, although it is superficially very attractive, this naive interpretation DOES NOT WORK. The reason is simple - it contains no probabilities, i.e., no Born rule. There are not “degrees of existence”; everything will exist regardless of how small its probability should be according to the Born rule. To put this another way, probabilities are for something to “happen” and here nothing has actually happened. Now I am aware that the foundations of the whole theory of probability are very unsure, even in the classical domain, but this should not prevent us from recognising that at this stage we do not have a satisfactory theory of the quantum world.

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One Mind Interpretation

To make progress, we can propose instead that, although the description of the physics is as given by the state above, with both terms, consciousness actually selects one term \([5,6,7]\). Normally this will happen at random with the weights given by \(|a|^2\) and \(|b|^2\), so that the Born rule is guaranteed. (In general to say that something happens at random requires that we give a weight, and there really are no other possibilities, so the Born rule is very natural.)

What we have now is I believe an acceptable solution to the measurement problem of quantum theory. It has several merits.

1. In principle it allows for consciousness to be “efficacious”, i.e., to be able to change the experienced world. In other words it can help to explain what consciousness is for. The point here is that there may be circumstances in which there is a quantum superposition in the brain which is not correlated to things outside the brain (like in the displayed state above). Then the selection, which perhaps need not be random, could determine the action that a person takes. This would correspond to our experience of free-will, and it would have an effect on the experienced world, although it would not alter the total wavefunction. In other words it would not violate the requirement (for some people) that physics is ‘closed’.

Of course, at this stage of our discussion (but not before) we have to make some assumptions about physical brains. In order for there to be the possibility of what we are describing here to happen we have to accept that brains are genuinely quantum systems that cannot be described by classical physics. I do not find this difficult. Although surgeons may see brains as warm wet matter, which from their point of view can be described perfectly well by classical physics, it remains true that there is no such thing as classical matter. Without quantum theory there would be no matter. To say that quantum effects, as we are describing here, cannot occur in brains, would be rather like telling a nineteenth century physicist who had just happened to have invented quantum theory that, even if it were true, there would be no possibility of ever detecting its effects in the real world.

2. The association of consciousness with “selection” seems to be something that others, from very different arguments, want to make. For a recent example Cotterill [8] writes “consciousness is for....evaluation and choice”.

3. There would be a unique “real”, i.e., experienced, world. The non-selected parts of the wavefunction would not really exist. To have an analogy here, imagine a sheet of white paper. By putting a suitable mask on this we could obtain a picture of say a person -see figure 4. Now different masks would produce different pictures (worlds) - indeed all possible pictures. It would be a misuse of language however to say that the sheet of white paper contained all the pictures - only the one selected by the mask would exist.

4. As with most versions of the “many-worlds” interpretations, this allows us to use anthropic arguments to explain the apparent coincidences necessary for our existence, but here it is with a unique world, rather then a scenario in which all things conceivable actually exist. The argument would be that in some sort of universal wavefunction, consciousness selects a part in which consciousness can exist.

Alternative Many-Views Models.

Several attempts have been made to give a meaning to probability when all experiences occur. For example, Albert and Loewer [3] and Albert [9] have suggested that associated with every person there are a large number of minds, and that each selects at random as with the single experience proposal above. Again this seems to work, but clearly the number has to be very large, otherwise there will be the possibility of meeting “zombies”. In fact Albert and Loewer suggest an infinite number, which I find hard to accept, because I am not sure that I really know what it means to have an infinite number of “objects” associated with a given person. Even worse is the fact that they want a continuous infinity. This runs into the problem that there is no natural measure on a continuous infinity: it just does not mean anything to say, for example, that “more” minds see one result than another. The same problem is met by Lockwood [4, 10] who proposes instead to have all “minds” labelled by a continuous parameter, e.g., \(0 < \lambda < 1\), so that a certain fraction of the line goes to one result, and another fraction to another, etc., in each case so as to give the Born rule. Again, this suffers from what seems to me to be the insuperable problem that there is no natural measure on such a line.
I should add that, on aesthetic grounds, I myself am more comfortable with the idea that there is one world, rather than having to accept that all things that can be actually are, however improbable the Born rule would make them. It just seems too much to have to believe that there really are people, holding conferences on physics and consciousness, etc., who have never experienced interference, or read about it or met anybody who had! They are going to have an awful shock next time they see a thin film of oil on water (or at least “a large part”, whatever that may mean in this context, of all of them are!)

Non-locality

Finally, we must discuss the issue of non-locality. It is sometimes stated that one of the advantages of the “many-worlds” style of solutions to the measurement problem is that they do not suffer from the non-locality which is all too evident in the Bohm model or in collapse models. To some extent this is true; the non-locality is removed from the physics because it only arises from the results of measurements, and so does not occur if there are no such results. However, it is still around; it has simply been removed to “consciousness”.

We can see this if we consider how consciousness can take note of the quantum probability. To do this we need to think a little more about how we locate the “patterns” that correspond to a given experience. Suppose that the quantum state is given by $|\Psi(x, y, t)\rangle$, where $x$ stands for the variables of particles in the brain and $y$ for particles in the system, the apparatus and the environment. The displayed state (3) above is just one particular example of such a state. To see a pattern we must project this onto a state of some presumed “consciousness basis” in the brain. If we denote this by states $|C_n(x)\rangle$, where the $n$ labels possible experiences, then the probability of the $n^{th}$ experience is, according to quantum theory, $|\langle C(x)|\Psi(x, y, t)\rangle|^2$. This however is not a number, but a function of the positions of all the other particles (some of these may well be thousands of miles away!). To get a number we must integrate over all these positions. This of course is horrendously non-local in realistic measurement situations. In other words, consciousness, if it is to “know about” probabilities, as it must if we are to obtain the Born rule, cannot be a local thing.

This is very important because it means that in the selection model there will only be one selection, not one for every separate person, a fact which ensures the essential property that all observers will make the same selection. Another way of saying this is to say that consciousness must be thought of as being ONE thing. This is something in which Schrödinger firmly believed, and it may be a contribution that quantum physics can make to the study of consciousness, thereby guaranteeing that quantum physicists continue to have a place at meetings like this.

Related Ideas

The idea that consciousness has to be introduced in order to understand quantum theory has been around since the 1920’s. Apart from the work mentioned above, recent contributions are due to Hodgson [11], Mavromatos and Nanopolous [12], Penrose [13], Page [14] and Stapp [15]. These models have many features in common, and in common, with the model that I am advocating here (in particular, the selection model shares many of the features discussed by Stapp in his recent articles [16,17]). The principle difference is that, in varying ways these authors have models in which the operation of consciousness is associated with some sort of explicit wavefunction collapse, so that the physics is not given exactly by the Schrödinger equation. It seems to follow that there will be observable differences between the predictions of these models and those of standard quantum theory (cf., for example, [18]). This is not necessarily a bad thing, but the models need to be made sufficiently precise in order that these differences can be calculated.

There may be a more serious objection in that a proper description of the collapse requires a new equation to replace the Schrödinger equation. Examples of such equations already exist of course (see [19] and references therein), but, at least in the context of the present discussion, they suffer from the fact that
there is no reason why the collapse effect has anything to do with consciousness. Rather the collapse is a universal phenomena, with the rate being very small, i.e. negligible, for microscopic systems, but being proportional to something like the number of particles, so that it is large in the macroscopic world. If we follow this line too closely then we are in danger of saying that consciousness arises, like rapid collapse, simply from having large systems. I believe Stapp, at least, would reject this suggestion, in my opinion rightly. Maybe things look different if the stochastic nature of the collapse process arises from something that is non-computable. This might provide a link with possible non-algorithmic aspects of conscious thought.

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FIGURE CAPTIONS

Fig. 1. A hypothetical neural pattern which Melinda interprets as the result +.
Fig. 2. A hypothetical neural pattern which Melinda interprets as −.
Fig. 3. A possible “sum” of neural patterns corresponding to the superposed state. But Melinda’s experience corresponds either to the pattern in fig. 1 or to that in fig. 2.
Fig. 4. A template that produces a pink man from a sheet of pink paper. Is the man already present without the template?

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4 Some people would regard this as a virtue of these models, but they would be unlikely to attend this conference.