# 432018 PHILOSOPHY OF PHYSICS (Spring 2002)

### Lecture 6: Interpretations that deny that there are determinate outcomes

**Preliminary reading:** Sklar, pp. 193-5.

We now turn to theories that deny the collapse postulate. As we saw in our taxonomy of solutions to the measurement problem, such theories tend to fall into two distinct groups. In this lecture, we shall examine the first of these groups, i.e. the theories which deny that quantum reality yields 'determinate outcomes' in the usual sense of the term. Then, in the next two lectures, we turn to the second of these groups, i.e. theories which deny that the states we use to represent quantum systems give us a *complete* description of such systems.

## 1 The way of illusion

Generally speaking then, the theories which fall into the first of these groups claim that the formalism of QM should only consist of our first four quantum mechanical postulates. As such, the dynamics of a quantum system is completely described by the Schrödinger equation, and any suggestion of superpositions 'collapsing' is an 'illusion'. Consequently, these theories have to explain our 'experience' of quantum systems, i.e. why it *appears* that we do experience 'determinate outcomes' as a result of measurements, without introducing new elements into the formalism.

We start by looking at Everett who initiated this way of thinking about QM. This leads us to consider 'the bare theory' which is a simplified version of Everett's position due to Albert. However, the main problem with both of these positions, as we shall see, is their refusal to be drawn on the 'nature of reality'. As such, we finish by considering two attempts to address this problem in an Everett-like theory, namely the many worlds interpretation of DeWitt and the many minds interpretation of Albert and Loewer.

### 1.1 Everett[1]

Following the work of von Neumann, there was little resistance to the collapse postulate. Until, that is, Everett published his work on QM. Unfortunately, due to the technical nature of Everett's work, we can't really discuss the details in this course and so we just outline his strategy. Once we have done this, we can look at 'the bare theory' which is Albert's simplified account of what Everett was trying to do. We should also note, in passing, that DeWitt's many worlds interpretation is chronologically prior to Albert's exposition of Everett, but conceptually it makes sense to do DeWitt later.

Everett's work is an attempt to formulate a *meta*-theory for QM, i.e. a theory which explains where the postulates of QM come from. In particular, he is particularly keen to:

- account for the fact that certain kinds of interaction, i.e. measurements, *seem* to give the 'determinate outcomes' which are normally accounted for by the collapse postulate.
- describe how the conventional interpretation of the probabilities in the formalism comes about.

His strategy is as follows:

- The *whole universe* is a closed system which has its own state vector and the evolution of this is described by Schrödinger's equation. That is, there can be *no* collapse of the state vector since *all* physical systems evolve in accordance with Schrödinger's equation as they are all part of the universe.
- In particular, what we normally think of as a 'measurement' yielding a 'determinate outcome' is just a certain kind of interaction between two physical systems whose evolution is described by the Schrödinger equation. As such, the measurement problem is *dissolved*.

[1] This Section contains a lot of material not discussed in the lecture.

- Everett's account of why things appear otherwise is based on the notion of a 'relative state' of the system. This basically works as follows: the universe and everything in it is in a huge superposition, and as such, there is no way of determining the *absolute* state of a given physical system. In fact, all we can do is determine the *relative* state of a particular physical system, i.e. its state relative to the rest of the universe. (This will become clearer when we discuss 'the bare theory' below.)

- To account for 'measurements', Everett *models* 'observers' as physical systems, say 'machines', which are capable of recording the results of an interaction between the 'measuring device' and the system being measured. Indeed, these 'machines' are capable of repeating measurements and communicating with one another so that they can assess whether they are in agreement about the outcome.

- When a 'measurement' is performed by such an 'observer', the interaction is governed by the Schrödinger equation. That is, the 'observation' causes the 'observer' to enter into the superposition that describes the system being 'observed', and as such, the 'outcome' that the 'observer' records can only be defined *relative* to this superposition. As such, there is no sense in which the 'observer' is in a determinate state after the 'measurement'.

- Indeed, as a consequence of this analysis, Everett claims that the 'determinate outcomes' which are normally accommodated by the collapse postulate are a *special* case. That is, they are due to a certain class of interactions which, like every other interaction, should be described by the Schrödinger equation.

- So, why do we *appear* to have 'determinate outcomes'? Well, as a result of the 'observation',[2] the state of the 'observer' *branches* into a number of different states.[3] And, each branch represents a different outcome of the 'measurement' through the *corresponding* eigenstate of the combined 'observer plus system' state. Needless to say, since there is no collapse, all of these 'branches' exist simultaneously in the superposition after such an 'observation' has been made. Thus, 'determinate outcomes' only *appear* to happen since each state of the 'observer' only appears in one branch. (Again, this will become clearer when we discuss 'the bare theory' below.)

- Lastly, Everett wants to account for the probabilities that figure in the quantum mechanical formalism. He does this by noting that the 'trajectory' of the memory configurations of an 'observer' form a 'branching tree'[4] with 'branches' occurring whenever the system undergoes an interaction with another system (be it a 'measurement' or not). So, neglecting the details, we just note that:

  - The probabilities are introduced by utilising a technique commonly used in classical statistical mechanics (i.e. in a way that is commonly practiced by physicists).
  - As such, the probabilities which we calculate using the quantum mechanical formalism match up (*via* a relative frequency view of probability) with the sequences of 'outcomes' which we would expect to find if we repeated the 'measurement' a *large* number of times.

  That is, Everett has a way of accounting for the distributions of 'determinate outcomes' which we 'appear' to find when we perform 'measurements'.

And this strategy, does seem to give a meta-theory for QM that does what Everett intended to do.

But, there is a **problem**:

[2]That is, the interaction between the 'observer' and the system being 'observed'.

[3]Note that, for Everett, this 'branching' occurs in the higher dimensional *configuration* space that describes the state of the *entire* system. That is, for Everett, the 'trajectories' which describe the evolution of the entire system in this configuration space 'branch' as a result of such interactions.

[4]In the higher dimensional configuration space.

> If the universe[5] is in a huge *superposition*, what can we ultimately say about the nature of *reality*? Everett seems to have taken the aspect of QM that we find most perplexing and, instead of trying to explain it away, has made it universal. That is, instead of trying to explain why the reality we observe is determinate despite the existence of 'unobservable' superpositions, our reality is now an *illusion* caused by the way in which the superposition that describes the physical world evolves.

This is the 'reality problem', and as we shall see, this is the main problem that the post-Everett interpretations have to address.

**Further reading:** H. Everett, *Relative State Formulation of Quantum Mechanics* in Review of Modern Physics, **29** (1957), pp. 454-62.

## 1.2 The bare theory[6]

The bare theory, which is an attempt to flesh out Everett's position simply asserts that when we perform a measurement on a physical system which is in a superposition, we just 'enter into' the superposition too. To see how this works, Albert considers a measurement on an electron ('$e$'-subscript) which is in a superposition of its $|\uparrow_x\rangle_e$ and $|\downarrow_x\rangle_e$ states, i.e.

$$c_1|\uparrow_x\rangle_e + c_2|\downarrow_x\rangle_e.$$

After a measurement of this electron's $x$-component of spin, the measurement apparatus ('$a$'-subscript) can be in either its 'measured spin-up state', $|\mathcal{M}[\uparrow_x]\rangle_a$, or its 'measured spin-down state', $|\mathcal{M}[\downarrow_x]\rangle_a$. Thus, after the measurement, since the apparatus has 'entered into' the superposition too, we now have the superposition

$$c_1|\mathcal{M}[\uparrow_x]\rangle_a|\uparrow_x\rangle_e + c_2|\mathcal{M}[\downarrow_x]\rangle_a|\downarrow_x\rangle_e.$$

Thus, in Everett-like terms, the *absolute* state of the combined 'electron plus measurement apparatus' system is this superposition, and the *relative* states which give us our 'illusory' determinate outcomes are $|\mathcal{M}[\uparrow_x]\rangle_a|\uparrow_x\rangle_e$ and $|\mathcal{M}[\downarrow_x]\rangle_a|\downarrow_x\rangle_e$.

### Explaining the 'illusion'

In the bare theory, Albert seeks to explain the nature of this 'illusion'. To do this, he considers a human observer ('$o$'-subscript) who examines the measuring apparatus and as a result of this, enters a state in which he either 'believes that the outcome of the measurement is spin-up', $|\mathcal{B}[\uparrow_x]\rangle_o$, or 'believes that the outcome of the measurement is spin-down', $|\mathcal{B}[\uparrow_x]\rangle_o$. As a result of this observation, he too enters into the superposition and so we have

$$c_1|\mathcal{B}[\uparrow_x]\rangle_o|\mathcal{M}[\uparrow_x]\rangle_a|\uparrow_x\rangle_e|\uparrow_x\rangle_e + c_2|\mathcal{B}[\downarrow_x]\rangle_o|\mathcal{M}[\downarrow_x]\rangle_a|\downarrow_x\rangle_e,$$

as the state of the combined 'electron plus measurement apparatus plus observer' system. Now, at this point, the obvious question to ask the observer would be:

> "What is your present belief about the electron's $x$-component of spin?"

But, there is no point asking the observer this question since he is in a superposition of a state where he responds 'spin-up' and a state where he responds 'spin-down'. As such, a world in which his responses are governed in this way is just as hard to understand as superpositions *simpliciter*.

So, Albert proposes that we ask our observer a different question, i.e.

> "Don't tell me whether you believe the electron to be spin-up or you believe the electron to be spin-down, but tell me merely whether or not you now *have* any particular definite belief about the $x$-component of spin of this electron."

Now, if the state $|\mathcal{B}[\uparrow_x]\rangle_o|\mathcal{M}[\uparrow_x]\rangle_a|\uparrow_x\rangle_e|\uparrow_x\rangle_e$ obtains, the observer will reply:

[5] That is, the collection of all physical systems.

[6] This Section contains a lot of material not discussed in the lecture.

"Yes, I *have* some definite belief at present."

and, of course, he will answer in precisely the same way if the state $|\mathcal{B}[\downarrow_x]\rangle_o|\mathcal{M}[\downarrow_x]\rangle_a|\downarrow_x\rangle_e$ obtains. Furthermore, since answering this particular question in this particular way is an observable property of the observer (i.e. '$o$') in both of these states, it is an observable property of any superposition of them (such as the one above) as well!

So, in summary, even though the observer above isn't in either one of the states associated with a definite belief about the state of the system, when he is asked the question above, he is going to report that he *does* have such a definite belief. That is, it would appear that the observer is going to be radically deceived about what his own mental state is. In this way, Albert seems to explain the 'illusory' nature of our experience of determinate outcomes.

Going further, suppose the observer carries out a further measurement of the electron's $x$-component of spin using a second measuring apparatus ('$a'$'-subscript) which also gives either a 'measured spin-up state', $|\mathcal{M}[\uparrow_x]\rangle_{a'}$, or a 'measured spin-down state', $|\mathcal{M}[\downarrow_x]\rangle_{a'}$. After this second measurement, the state of the combined 'electron plus two measurement apparatus plus observer' system will be

$$c_1|\mathcal{B}[\uparrow_x]\rangle_o|\mathcal{M}[\uparrow_x]\rangle_a|\mathcal{M}[\uparrow_x]\rangle_{a'}|\uparrow_x\rangle_e + c_2|\mathcal{B}[\downarrow_x]\rangle_o|\mathcal{M}[\downarrow_x]\rangle_a|\mathcal{M}[\downarrow_x]\rangle_{a'}|\downarrow_x\rangle_e.$$

And now, suppose that we ask this observer the following question:

> "Don't tell me what the outcomes of either of those measurements of the electron's $x$-component of spin were; just tell me whether or not you now believe that those two measurements both have definite outcomes, and whether or not those two outcomes were the same."

Using arguments similar to the ones given above, the observer's response to this question will be

> "Yes, they both had definite outcomes and both of those outcomes were the same."

even though, as a matter of fact, and on the standard way of thinking, *neither* of these two experiments had any definite outcome. And, clearly, similar questions can be asked and answered using similar arguments regardless of what kind of experiment is being performed and which observers are being asked. When such a superposition obtains, i.e. when there is no matter of fact about the electron's state nor is there any matter of fact about the observer's beliefs about the electron's state, Albert says that the observer 'effectively knows' what the electron's state is.

**Explaining the probabilities**

Albert then goes on to explain how the probabilities enter into the theory on this account. Assume that we have $N$ electrons and we ask our observer to measure the $x$-component of spin of each one. Then, at the end of this sequence of measurements, we ask him the following question:

> "Don't tell me what the outcome of any of your $N$ measurements was; tell me merely whether or not you believe that each one of those electrons has a definite $x$-component of spin and, if you do, tell me also what *fraction* of those electrons turned out to be spin-up in the $x$-direction."

As we have seen, the answer to the first question is going to be

> "Yes, I believe that each one of those electrons has a definite $x$-component of spin."

and, at this point, the observer 'effectively knows' the state of each of these $N$ electrons.

But, of course, the observer won't be able to give a coherent answer to the second question. That is, in the same way that the observer can talk about having definite outcomes but can't actually specify what those outcomes are, the observer can talk about definite outcomes for the $N$ electrons but can't actually specify what those outcomes are. And, this is simply because there is no fact of the matter about what the outcomes are since the observer has beliefs which are part of the superposition. Thus, at best, the observer can only answer this question in a variety of different and incompatible ways.

Now, Albert notes that, in the limit as the number of electrons being measured (i.e. $N$) goes to infinity, something strange happens. In this limit, the superposition will *approach* a state in which the observer *will* answer the second question in a perfectly *determinate* way! That is, the observer will say that *half* of the electrons turned out to be spin-up in the $x$-direction — which is exactly what we expect from our ordinary quantum mechanical way of thinking about this situation.[7] Indeed, this analysis can be generalised to the extent that:

> If an observer performs the same measurement on an infinite number of identical physical systems then, even though there is no fact of the matter about what the observer takes the outcomes of any of these measurements to be, as the number of measurements carried out goes to infinity the state of the 'world' will approach a state in which the observer reports that the *statistical frequency* of any particular outcome will be determinate and in agreement with the quantum mechanical predictions about what that frequency ought to be.

That is, in the long run, these statistical frequencies agree with the probabilities we calculate in QM.

**Summary**

Thus, following on from Everett, Albert appears to have an explanation of why we *appear* to have determinate outcomes even though there is no fact of the matter due to the continued presence of superpositions. Furthermore, Albert seems to be able to give an account of how these 'illusions' give rise to the probabilities which we expect from the quantum mechanical formalism.

But, there are **problems** with this theory:

- Even though we can ask certain questions and get certain answers, there are, as a matter of fact, no determinate outcomes. As such, the reality problem doesn't seem to have been adequately solved.
- Also, given that the observer being questioned is always in a superposition of belief states, who exactly is asking all these questions? In particular, why don't they just enter into the superposition too?
- The 'illusions' we want to explain involve determinate outcomes like 'the electron is spin-up in the $x$-direction', but the questions we are 'allowed' to ask in the bare theory never give us such specific information. As such, the bare theory only seems to succeed in explaining our 'illusions' about outcomes which don't really concern us.
- Do we really want to say that the probabilities which we calculate using Born's rule are what we expect in some infinite limit? After all, if that *is* the case, why do we have any reason to believe in QM after the finite number of measurements that have been performed up to now?

**Further reading:** D. Z. Albert, *Quantum Mechanics and Experience* (Harvard University Press, 1994), pp. 116-25.

## 1.3 The many worlds interpretation

Everett's position was usually taken to be a bit obscure, but DeWitt proposed what was to become the canonical explanation of what Everett meant. This is DeWitt's many worlds interpretation of QM, which essentially claims that:

- When a measurement is performed on a system which is in a superposition of $n$ different state vectors (each of which represents a possible outcome of the measurement), the world 'splits' into $n$ worlds.

[7] The reasoning behind this strange 'fact' is illustrated in Footnote 6 on p. 122 of Albert's book *Quantum Mechanics and Experience*.

- Each of these worlds contains the system in a state corresponding to one of the possible outcomes of the measurement (so the system in each world is now in one of the states described by a state vector in the original superposition). That is, for every possible outcome of the measurement, there is now a world where that outcome was realised.

- These worlds are *real*, i.e. just as real as the one we inhabit.

But if this is the case, we can ask: Why do we *never* see the 'splitting'? To which, DeWitt replies, because:

> when a measurement is made, 'we' (the observers) end up in all of the $n$ worlds. For example, when we take an electron and measure the $x$-component of its spin, there is a world in which 'we' measure the spin and it's definitely up and there is *another* world where 'we' (a 'counterpart' of us?) measure the spin and it's definitely down. However, we are always in our own world and as such we have no contact with the other world in which 'we' (our 'counterpart'?) has made the measurement.

In fact, it is interesting to note that the 'splitting' of worlds in this interpretation plays the same *role* as the collapse postulate in the interpretations we considered in the last lecture. That is, the 'splitting' produces 'successors' of measuring devices (including observers) which, as with collapse, record the determinate outcome of a measurement.

But, inevitably, there are **problems**:

- *Philosophically, there is the ontological 'cost':* After all, in your metaphysics, how many worlds do you want to exist? Of course, when considering the notion of a *possible world* in a discussion of *modality*, a follower of David Lewis could maintain that there are *real* possible worlds (and modal talk is talk about our *counterparts* in these worlds), and hence he may find this interpretation quite reasonable. But, in Lewis' account the possible worlds are all out there all of the time, running (say) in parallel with ours. That is, there is no notion of 'splitting' and, in fact, according to Lewis there can be no *causal* connection between these worlds! Furthermore, Lewis' theory is a very unpopular (and some would say untenable) account of the possible worlds required as a basis for our modal discourse. Clearly, the 'possible worlds' needed in this interpretation are even more problematic and yet no *metaphysical* explanation of what is going on has been provided.[8]

- *Physically*, there seem to be two major problems:
  - *It relies on a dynamics described by Postulate 3, but appears to be inconsistent it:* Basically, according to the Schrödinger equation, the total mass of the combined 'physical system plus measuring apparatus' system is the same before and after the measurement. Indeed, the same goes for the total number of particles contained in the system (since this is not changed by measurement). However, according to the many worlds interpretation, a measurement *literally* results in the creation of new worlds, i.e. there is a huge increase in both the mass associated with the combined system and the number of particles involved.[9] (Although, to be fair, in *each* created world these quantities are clearly the same. There is only more 'stuff' when we look at these quantities 'over' several of the created worlds and it is not clear how the Schrödinger equation should be applied 'across' such collections of created worlds. So, at the very least, to make this point we need an account of how these worlds are related, if indeed, they are.)
  - *It doesn't provide an account of the probabilities in QM:* According to the many worlds interpretation, it is *certain* that all outcomes of the measurement will occur (in some world) and will be observed by 'successors' of the current observer (in that world). But, if that is the case, what are we doing when we calculate the *probability* of a particular outcome using Born's rule? (Of course, someone who believes in the many worlds interpretation

[8] Or, to bring in an alternative metaphysics, recall the 'branching time' hypothesis that is sometimes utilised in discussions of time-travel. Would this give us a more plausible account of what is going on?

[9] Also, what about everything else that was contained in the world prior to the measurement?

could say that some of the worlds into which the superposition 'splits' are more *actual* than others.[10] In this way, the 'probability' could be identified with the probability that the actual world will follow a particular path through the 'split'. However, this suggestion is very *mysterious*, especially since 'actuality' is not normally something that comes in degrees. Indeed, what distinguishes the more actual worlds from those that are less actual? Moreover, this suggestion seems to give up the central feature of the many worlds interpretation, namely that the state vector is supposed to be a *complete* description of the physical world.[11])

**Further reading:** B. DeWitt, *Quantum Mechanics and Reality* in Physics Today, **23** (1970), pp. 30-5.

## 1.4 The many minds interpretation

The many minds interpretation is, in effect, a further development of the many worlds interpretation. Once again, the Schrödinger equation governs *all* physical processes and as such, there is *no* collapse. So far, this is similar to Everett's position, and we recall that within this, it seems that macroscopic measuring devices and observers themselves *can be in superpositions*. So, as before, the main difficulty this view seems to face is the following: we never see macroscopic objects in superpositions. Furthermore, we don't have any experiences which correspond to 'us' being in a superposition. (For example, after a spin measurement, we are never in a superposition of states such as 'thinking that the spin is up' and 'thinking that the spin is down'.)

Albert and Loewer proposed the many minds interpretation to try and overcome this difficulty. To do this, they claim that QM applies to our *brains* (for example, during measurements). Their strategy is as follows:

- With each *brain* state of an individual, associate a certain *mental* state. (For example, a *belief* that the electron is spin-up is such a mental state.)
- Then, each component of a superposition will contain a state of the system, a brain state and the corresponding *mental* state. For example, a superposition of the $|\uparrow_x\rangle_e$ and $|\downarrow_x\rangle_e$ states of an electron ('$e$'-subscript) is normally written as:

  $$c_1|\uparrow_x\rangle_e + c_2|\downarrow_x\rangle_e,$$

  but, if we are to take the brain states ('$b$'-subscript) and the corresponding mental states into account, we have

  $$c_1|\mathcal{B}[\uparrow_x]\rangle_b|\uparrow_x\rangle_e + c_2|\mathcal{B}[\downarrow_x]\rangle_b|\downarrow_x\rangle_e,$$

  where the brain state

  - '$|\mathcal{B}[\uparrow_x]\rangle_b$' has the corresponding mental state of 'believing that the spin is up', and
  - '$|\mathcal{B}[\downarrow_x]\rangle_b$' has the corresponding mental state of 'believing that the spin is down'.
- We then invoke a crucial distinction, i.e. that
  - *Brain* states are physical. As such, these evolve deterministically according to Schrödinger's equation.
  - *Mental* states are non-physical states in the *mind.* Here, 'minds' are non-physical — in the sense that they are *not* quantum mechanical systems — and so their evolution is *not* governed by Schrödinger's equation. Instead, mental states evolve *probabilistically.*

  In particular, even though *brains* can be in superpositions (since they are physical), *minds* can't be (since they are non-physical).

[10] Note that 'actual' is yet another term from philosophical discussions of modality.
[11] Since we would need something else (possibly related to 'degrees of actuality'?) to get the probabilities.

- Thus, after a measurement, the observer ends up either in the mental state 'believing that the spin is up' or the mental state 'believing that the spin is down'. That is, the observer's final mental state is always a state of *determinate belief*, and not some kind of superposition. (Which is pretty much what we wanted to avoid.)

- Lastly, Albert and Loewer want to account for the probabilities that are part of the quantum mechanical formalism. To do this they note that, at the end of the measurement, the observer's brain and the electron are *still* in the superposition

$$c_1|\mathcal{B}[\uparrow_x]\rangle_b|\uparrow_x\rangle_e + c_2|\mathcal{B}[\downarrow_x]\rangle_b|\downarrow_x\rangle_e,$$

  even though the mental state is now determined, i.e. not in a superposition. (Remember: brains are governed by the Schrödinger equation, minds aren't.) The probabilities are then interpreted by saying that:

  - the proportion of observers whose minds are in the mental state 'believes that the spin is up' is given by $|c_1|^2$, and
  - the proportion of observers whose minds are in the mental state 'believes that the spin is down' is given by $|c_2|^2$,

  in accordance with Born's rule. That is, before making the measurement, each observer's mind can 'know' that the post-measurement physical state (i.e. the state of the combined 'brain and electron' system) will still be in a superposition, and so can assign a probability of $|c_1|^2$ ($|c_2|^2$) to *its* observing spin-up (down).

Thus, their interpretation does seem to explain why we don't experience superpositions and account for the probabilistic nature of the predictions of QM.

Furthermore, we should note that the many minds interpretation avoids all of the difficulties associated with the many worlds view:

- *Philosophically*, we no longer have to worry about *the ontological cost*. (As we don't have to worry about any 'new' worlds being created. Nor do we need any 'deep' metaphysics to underwrite this talk of many worlds.)

- *Physically*, we no longer have to worry about:

  - *Possible inconsistencies with the dynamics.* (As nothing new is being created all the relevant quantities are being conserved, i.e. the combined 'physical system plus measuring apparatus' system is the same before and after the interaction.)
  - *Not having an account of the probabilities in QM.* (The probabilities are introduced as above, and they don't depend on any untenable distinction between actual and non-actual worlds, or indeed, degrees of actuality.)

which is also good.

But, there are **problems**:

- *Philosophically, there is still the problem of what a mind is:* Albert and Loewer seem to have adopted a position on the mind-body problem which is just as problematic as Wigner's. Futhermore, since a sequence of measurements (of an electron's position, say) can have an infinite number of outcomes, we get an infinite number of *minds* (i.e. a single brain with infinitely many different corresponding mental states) as each outcome gives rise to a brain being in a corresponding mental state. Thus, Albert and Loewer have just chosen to proliferate minds instead of worlds!

- *Physically*, there seem to be two major problems:

  - *The probabilities are introduced by fiat.* Albert and Loewer just mimic the strategy for introducing probabilities in the fourth postulate of our quantum mechanical formalism. (Basically, they just assert that the probabilities can be obtained by using Born's rule.) However, since minds are *not* physical systems, why should this strategy apply to them?

– *Observers can have false beliefs:* Suppose that an electron is in a superposition of its spin states and an observer is going to measure its spin. According to the many minds interpretation, after the measurement has been performed the observer believes that the electron has spin-up (say), but the electron is *still in a superposition* and as such, the observer's belief is, strictly speaking, *false*!

**Further reading:** D. Albert and B. Loewer, *Interpreting the Many Worlds Interpretation* in Synthese, **77** (1988), pp. 193-213.