The Solution to the Measurement Problem

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There has been a lot of talk about the measurement problem. While the physics of it has been (at least mostly) rigorous, the underlying philosophy has been nothing short of a complete catastrophe. This paper will establish the true philosophical context and integrate the appropriate science into it, as it should have happened from the beginning. Bad philosophy didn't allow it. I also highlight the false dichotomy underlying the measurement problem so that it can be detected more easily for those who do not engage with philosophy in an extensive manner.

Introduction

The topic at hand may strike the reader as unanswerable in principle, unanswerable in practice or simply as one of the most controversial topics with all faith lost. But the whole purpose of this article is to prove that all of these three notions should be the controversial ones instead of the measurement problem itself. In the following arguments, I will appeal exclusively to ideas that the rational reader will identify as completely uncontroversial and I will prove that

1. there is nothing mysterious about the measurement problem
2. there is nothing unanswerable about it
3. the answer is beautiful, elegant, straight-forward and philosophically sound
4. the answer does not involve adding anything to our knowledge other than a guided integration of the facts, neither a mysterious metaphysical entity, nor an unfounded relation or principle

by simply putting them together.

Metaphysics and Epistemology

Since Aristotle we know that everything is what it is. We should, at least. When we use our consciousness it doesn't take a lot of method to identify that there is something that exists. Clearly something exists of which our consciousness is conscious. What can be said about it? That it is, as Leonard Peikoff puts it eloquently. And whatever it is, it has an identity. It having an identity (which means properties) is a precondition to us observing them. You can't observe something that doesn't exist (in some form). That is true whether we talk about the whole of existence or whether we focus on just some part of it. Everything is what it is, everything has properties and the importance of these general metaphysical and epistemological principles will become more evident as I go from abstract philosophical principle to concrete philosophical proposition and then after that, in applying these philosophical facts, from abstract physics principle to concrete physics proposition.
The process involved will be a process of reduction since I am going to take these broad principles and reduce them further and further to what is directly observable. While the existence of something is a direct observation, the conceptual grasp of that fact is highly abstract compared to, let's say, the conceptual grasping that is necessary to understand that whenever we measure something we see some outcome. The latter can be seen as a conceptual instance of the former. I am not, however, proving that something exists. I am just saying that the abstract principles that I will be proving will be justified through reduction. Now, the promise to fulfil is an integration of facts. But the integration process is simply the reversal of the reduction process. It would be like this paper read from end to start. But the order does not matter.

Complex Numbers

In General

Complex numbers never stand for anything in reality directly since nothing has an "imaginary part" and the fact that many things can be solved or described beautifully using them is not evidence of them having a metaphysical quality by itself. Complex numbers are an idea, a concept. They are a concept that relates concepts to each other. For example, we use the concept of parabolas to describe the (frictionless, non-relativistic) trajectory of a tennis ball shot from a tennis ball machine. But to find the points at which the ball reaches a certain height we need complex numbers. So they relate two physical (trajectory and height) or two mathematical (equation and solution) concepts to each other. They are sort of an "intermediary" concept or a more abstract concept than the concepts they connect. Relation is an abstract concept and every type of relation is some subtype of this abstract concept.

In Quantum Physics

The exact same principle applies to complex vector spaces, complex vectors and complex functions. They stand as intermediary concepts relating to other mathematical concepts that we can use to describe the world directly. The fact that quantum physics uses complex numbers to derive probabilities does not add a metaphysical side to them in some unspecified, mystical way. The nature of probabilities is the topic of the next section. It adds nothing since we mean nothing with them in the real world just as we don't mean anything in the world with the intermediate complex variables we use to solve the quadratic polynomial to describe the things we do "mean" in the world (a tennis ball). There is no connection between complex numbers and the real world that does not involve another mathematical concept inbetween. In that sense those more concrete mathematical concepts are the "intermediate" ones. But the latter distinction will not play a role here.

Probabilities

Similarly, probabilities do not describe anything metaphysical in the real world. There is no such thing as a chunk of probability lying around in your closet next to your umbrella. They are, again, concepts that relate other concepts to each other. They connect mathematics and uncertainty. Statistics can be used to purely describe a present or past circumstance—for example when we say that exactly 65% of all people who were eligible to vote had done so in some election. When we make statements about the future, however, there is another principle involved.

The Principle of Induction

Contrary to popular belief, the process of induction does not involve an extension of knowledge into (previously) unknown territory. The principle of induction is the process of generalizing observations to make a statement about the things observed as a category. To again quote Leonard Peikoff, from "These fires burn when I touch them." to "Fire by its nature burns." It is the formation of a connection between some aspects of an entity to the type of entity itself. For example when we release an object from our hand we can observe it fall to the ground. But we can recognize from further observation that whatever we take it falls down. So by the very nature of an object being a (physical) object it falls to the ground on earth. This of course ignores the effect of the atmosphere on helium balloons etc where the phenomenon (and, epistemologically, the principle) involved is understood in exactly the same way, i.e. by connecting the observed attributes of the entities to their nature as a whole, the helium balloon as well as the atmosphere. This process relates to observations already made. It is a process of identifying a principle, not the application of the principle to new cases (which would be deduction, for completeness).

Probabilities as Deduction

Saying that the next fire will burn may be an evident fact once we have observed it many times already. But it is nevertheless the application of a generalization made using previous instances to a new instance and could therefore be wrong. (The condition under which it is wrong, for example when wearing gloves, of course couldn't contradict the observations already made.) This is the only basis for predictions we have, i.e. some attribute of an entity that was generalized in the past on the basis of observations about that entity and the inference that that type of entity will behave in the same way in the future. When we say that 65% of people who were eligible to vote had done so we are not making an induction about the people eligible to vote because we know that this number is completely malleable. In fact, an induction about man's ability to choose his actions stands in the way. Combining statisics and induction, however, is a very natural thing to do when dealing with things outside of human behaviour (and often even human behaviour, e.g. for studying culture and predicting history). There are of course other applications of deduction that have nothing to do with probabilities. The point here is that predictions and probabilities are a form of deduction, not the other way around. The expansion of knowledge that deduction provides may follow a different axis than the time axis, but in the context of predictions and probabilities it always follows the time axis. Solving a mathematical equation, for example, is deduction but is neither a prediction nor does it necessarily involve probabilities.

An Example

When we ask ourselves whether it will rain in the near future the only thing we can do is aggregate facts about the current situation relating to entities and their attributes of which we know that they are connected to rain. We know that rain drops from clouds. But not every cloud is a rain cloud. Which one is? This, again, is some aggregation of observable facts. And so we aggregate weights in favor of and weights against the proposition and we come to the conclusion that it's 41% likely that it will rain because 41% of the evidence supports it while 59% contradicts it.

Pure Epistemology

Probabilities are not metaphysical. They don't lie around in your wardrobe, as mentioned earlier. What we mean by them are weights of knowledge and we only need them when the weights aren't all on one side. When we observe every single human dying we don't need to talk about the probability of ourselves dying some day. There is nothing that suggests the opposite and a whole history that supports the idea. Probabilities in quantum physics are not an exception when it comes to the nature of probabilities.

Probabilities in Quantum Physics

This whole paper could end here at this point. Since even the "Copenhagen interpration" only has a problem with misinterpreting probabilities as metaphysical. (The wave function/quantum state does not collapse if it isn't real. And it's not real if it's simply the complex numbers we use to calculate observations/probabilities.) But it shouldn't. It is only appropriate to reduce all the mentioned philosophical principles to everything that we know about quantum physics and to integrate that knowledge fruitfully to the furtherance of philosophy, science and their interplay, to set an example in the application of the philosophy of science to science.

Superpositions

Some remarks about superpositions are in order before we transition into the physics of quantum physics. Nothing in the history of quantum physics suggests that the superposition is metaphysical. While the superposition is certainly real mathematically and the superposition state has an overlap with the states of which it consists mathematically, that isn't true in reality. As established earlier, the quantum state as a complex-valued mathematical entity does not represent anything observable at all in reality. As I have also explained already, the fact that we only have probabilistic knowledge about what outcome we will measure in a measurement also doesn't qualify the superposition as metaphysical since probabilities are never metaphysical. The last and probably least understood parts of quantum physical superpositions not being metaphysical are

1. the mathematical overlap.
2. the interference phenomena.

The relevance or irrelevance of the mathematical overlaps will be covered in detail in the second part of this paper about the theory of quantum physics.

The False Dichotomy of the Interference Phenomena

It is in reference to the interference phenomena that the false dichotomy, the false dilemma of the measurement problem is constructed.

The false dichotomy says either you

1. assume directly that the mathematical superposition is metaphysical and therefore the interference phenomena are perfectly explainable. Then, however, you have to assume that something magical happens when you measure, since you assume something metaphysical (a mathematical component which you declare metaphysical) suddenly vanishes in that moment.

2. assume that the system is actually in one of the component states of the superposition state and that the probabilities for the outcomes that correspond to the mathematical components describe our uncertainty about which the system is in. Then you can explain the metaphysical nature of the measurement, but your assumption is in contradiction with our observation of interference.

Observe that there is one assumption that both of these alternatives share: Both ascribe metaphysical reality to some mathematical component. The first case ascribes metaphysical reality to both components. The second ascribes metaphysical reality to only one. The default position should be that the mathematical superposition is simply a state in its own right. There is no evidence whatsoever that some part of the mathematical superposition has any metaphysical reality. But these claims are not only arbitrary. The alternatives above are both wrong. The first declares probabilities metaphysical which is not what probabilities are or can be and the second is in direct contradiction with our observations. None of them is the default position anyway which is to acknowledge what you know and what you don't know. We know what we measure (interference and concrete measurement outcomes, not one) and the theory is constructed (including mathematical superpositions) to fit the measurements. The theory itself (the mathematics) cannot be proof of anything. It's the other way around. It's the observation that gives the mathematics any validity whatsoever. To then infer something from the mathematics that is not indicated by the evidence in any way is to engage in circular logic. You have to just assume what you hold as true and then "prove" it by referring to the fact itself. Both false alternatives explain to you that our mathematical descriptions of reality have a certain metaphysical reality because, after all, our mathematical descriptions have a certain metaphysical reality. There is nothing to justify this.

The Resolution

To say that the quantum state represents our knowledge of reality is perfectly rational. But the only connection to reality is through the probabilities we compute with it and observe. That is true in any case. It is not rational to ascribe metaphysical reality to the parts of the quantum state. There is no justification for it and, in fact, it stands in violent contradiction to philosophy and the observations from our physics experiments. There is also no necessity for it. There is necessity to not do it.

Quantum Physics

Many of the above claims will become much clearer through the theory of quantum physics. I will call the quantum system that represents the measurement apparatus A and the system that is being measured S. I will also ignore normalization terms.

What a Measurement is and is not

What it is

A measurement must entangle A and S maximally. For example for a two-state system with states $|0\rangle$ and $|1\rangle$ we would have

$$|0\rangle_A \otimes |0\rangle_S + |1\rangle_A \otimes |1\rangle_S$$

after the measurement. Why? That's the case because the apparatus must correlate perfectly with the system in terms of probabilities if it is a perfect measurement and we know that to be the case for a state of this kind (maximally entangled) and no other. That gives us a definition for measurement.

What it is not

The above does not imply any asymmetry in nature between system A and system S. In fact, quantum physics says that there is no such asymmetry [1]. Nor is there any collapse implied in the above definition. In fact, a superposition is created and not collapsed in that process. And if another observer observes the system perfectly it too gets entangled into the superposition. A measurement, in its mechanics, is no different from any other interaction between two quantum systems. But surely the state has to collapse to one of the branches at some point? Why? We have already established that the attribution of a metaphysical reality to parts (some or all) of the mathematical superposition is completely arbitrary and even in contradiction with everything we know.

Relational or Epistemological?

Carlo Rovelli describes the consequences of taking the theory of quantum physics seriously in his papar called "Relational quantum mechanics" [1]. It leads to the symmetry between "observer" and "observed" and a dropping out of the necessity to talk about any collapse. His conclusion is that quantum physics is "relational" in the sense that you can only talk about the "information" one system has of another. But my claim is the following. It is not relational. Our description is relational, just like our description is also complex (in the sense of complex numbers). Two things should be obvious:

1. An unconscious system knows nothing.
2. Information always refers to knowledge.

The second point may seem as highly controversial at first glance. But really we mean nothing else with the concept. An unordered system does not have any less "information" than an ordered system. It only evades our effort to interpret it as being capable of storing knowledge by its current state. Does a two-state system have less information than two state systems? Yes. But what we mean is that it can store more knowledge. It is purely conceptual. Information is not a property of nature. It is an abstraction and describes not a property of a physical system but a state of knowledge. A system that is less predictable behaves more probabilistically and the epistemological nature of probabilities I have already explained. So the metaphysics of quantum physics is even weaker than Carlo Rovelli suggests. While he suggests that the relationships are real and implies some kind of relative metaphysics, I suggest that it is simply our knowledge of relationships that is at the core of quantum physics and that our knowledge is limited to relations between systems which, again, is purely conceptual and epistemological. It is all that we know. It is as simple as that.

Quantum States are unique anyway

What if I told you that there exists a logical proof that shows that any two quantum states are incompatible with another and that, therefore, a superposition cannot be considered metaphysical? There exists such a proof. It's called the PBR theorem [2]. What it does effectively is to show that any pair of quantum states, let's say

$$|\psi\rangle_1 = |0\rangle$$
$$|\psi\rangle_2 = |0\rangle + \epsilon\,|1\rangle$$

where ϵ is an arbitrarily small number, have a probabilistic overlap of 0 even if they are arbitrarily similar (but not equal). Now, what is meant with probabilistic overlap is the following. If we assume that the quantum state describes a probability distribution over physical states (which is fair since the quantum state only gives us probabilistic information in general) the assumption that these probability distributions have an overlap at all leads to a contradiction with what the theory of quantum physics says. That is because for every pair of quantum states a combined measurement of the two systems exists with one outcome for a combination of the two states $|\psi\rangle_1$ and $|\psi\rangle_2$ having a probability of 0 which is impossible if the underlying probability distributions have any overlap at all. Why is that? If they have an overlap it means the states of both systems can come from that overlap region. In that case, the physical state of the system is compatible with either of the quantum states $|\psi\rangle_1 |\psi\rangle_1$, $|\psi\rangle_1 |\psi\rangle_2$, $|\psi\rangle_2 |\psi\rangle_1$ or $|\psi\rangle_2 |\psi\rangle_2$. Quantum physics saying that we can always rule out one case perfectly is in direct contradiction with that. I had promised to explain the relevance or irrelevance of the overlap of quantum states. On the one hand the mathematical overlap of quantum states is irrelevant in the sense that as big as it may be (for example orthogonal states) the superposition of the two states is still not metaphysical. The PBR theorem says that the supoerposition is a different state. On the other hand there is no "fuzziness" between quantum states. Even if the overlap is arbitrarily small we have probabilistic independence. Probabilistic independence is simply implied from the lack of overlap in the probability distributions.

So every quantum state describes different physical states. Even the most similar quantum states describe completely different physical states. The superposition of two arbitrary quantum states describes completely different physical states than the quantum states it consists of mathematically.

Conclusion

So is nothing real?

To say that because quantum physics only describes our knowledge of the world nothing is real is to, again, engage in the fallacy that probabilities are metaphysical. It's not our mind that decides what exists. It's our mind that discovers it. And if we haven't discovered it, it is not barred from existing.

Bad Science

Bad philosophy is real and bad science is real as a consequence. Sticking to what the evidence shows us should always be the default position. Most importantly, science cannot and does not contradict fundamental epistemological principles. Words have meanings and the word probability is not an exception. Probabilities are not the tendencies of a system that behaves magically but weights of evidence. Nothing that has been established from observation suggests a magical behaviour of quantum systems. It is only the fallacy that probabilities imply magic that generates the mystery around the so-called measurement problem of quantum physics.

No Mystery

I hope to have convinced the rational reader that quantum physics does not involve any mysteries and that probabilities are not forms of magic but concepts of epistemology that allow us to grasp our incomplete knowledge of a certain entity mathematically.

Recapitulating my Solution

Here are the most important points:

1. Mathematics is an epistemological tool and does not imply metaphysics. The evidential basis of quantum physics does not necessitate and therefore does not justify the interpretation of the mathematical components of the quantum state as real.
2. Probabilities in particular always describe knowledge and never magic. Therefore the fact alone that quantum physics involves probabilities does not imply the measurement problem.
3. There is no conflict between the existence of interference phenomena and an epistemological understanding of quantum physics. The epistemological understanding actually removes the necessity of assuming some sort of magical collapse in order to acknowledge the evidence for interference phenomena.
4. There is no way in which the theory of quantum physics implies a "collapse of the wave function" other than a misinterpretation of probabilities as metaphysical.
5. Taken at face value, the theory of quantum physics implies the exact opposite of an abrupt change when a measurement happens. It implies a gradual entanglement between systems and the notion of a collapse is, once again, simply a misguided perspective.
6. There even exists a logical proof that the mathematical superposition cannot be and is not real and metaphysical. Every two quantum states describe different physical states and therefore every superposition of quantum states describes distinct physical states from its constituent quantum states.

Therefore quantum physics simply describes our knowledge. A metaphysical interpretation of the mathematics is not and has never been justified. It is reality that gives the mathematics any metaphysical meaning, not the other way around.

References

[1] C. Rovelli, "Relational quantum mechanics," *International Journal of Theoretical Physics*, vol. 35, pp. 1637–1678, August 1996.

[2] M. F. Pusey, J. Barrett, and T. Rudolph, "On the reality of the quantum state," *Nature Physics*, vol. 8, pp. 475–478, May 2012.