You, me, and quantum measurements

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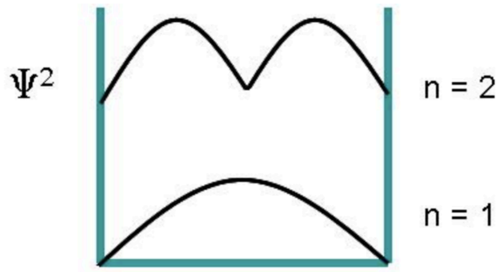
In this essay, I argue that quantum mechanics is incomplete, as the Schrödinger equation is unable to provide a complete (specifically, a continuous) account of how wave functions evolve. Attempts to make quantum mechanics coherent necessitate consciousness as part of the wave function update process. Supporters of a consciousness-involved approach argue that during the wave function collapse, knowledge of the wave function is preserved via our consciousness, thus making the update continuous, thereby making quantum mechanics coherent. This conclusion implies that our consciousness has a role to play in the behaviour of elementary particles. This runs counter to our desire for physics and our understanding of the natural world to be independent of observers (more precisely, it would necessitate an anthropocentricity of quantum mechanics). Thus, the debate of incompleteness turns on whether this consciousness-involved approach succeeds, and whether its commitments are acceptable.

To begin, I will provide a brief outline of what quantum mechanics is. The aim of quantum mechanics is to give an account of how elementary particles behave (i.e. to describe the evolution of a particle and its physical properties, e.g. its mass, energy, spin, &c). Elementary particles are particles that cannot be subdivided into further, more fundamental parts (CERN, n.d.). For this essay, I accept that photons, electrons, quarks, &c, exist. Thus, the scope of quantum mechanics is of the microscopic world, in contrast with classical mechanics' description of the macroscopic world. This distinction will be relevant later. We describe particles by using wave functions. Wave functions are mathematical descriptions of particles. One can apply quantum operators on these wave functions to obtain special numbers (eigenvalues) which inform us of the state of a particle. Particles have many states; for simplicity, let us only focus on its spin state. Suppose we have one electron. It can either be in a spin up state, or a spin down state. To determine its spin state, we apply the spin operator on the electron's wave function, and get an eigenvalue corresponding to the state we care about. For instance, we expect to read a "1" if it is in a spin up state, and a "-1" if it is in a spin down state. In real life, to measure a particle's state, we have measuring devices which read "up" or "down" when a particle is either up or down (this is a generalisation, but it will suffice).

Figure 1

The probability distribution(s) of an electron in a box

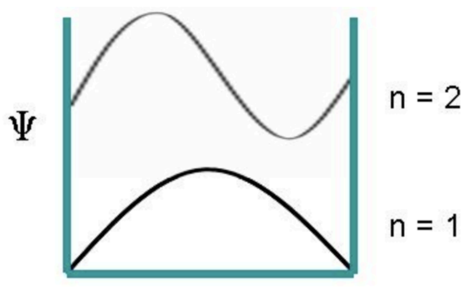


Note. Only energy levels of n = 1 and 2 are drawn, when in principle, all energy levels n = 1 and greater are present (LibreTexts, n.d.).

Apart from states, particles evolve over time (e.g. a particle moves from place to place, across time). Suppose we trap an electron in a box. We know it must be somewhere in this box, but where exactly? Quantum mechanics asserts that we do not know for certain where exactly the particle will be. The square of the wave function gives us the probability distribution of a particle. Figure 1 has two probability distributions for a single electron, as an electron can have many energy states. Let us focus on n = 1. From the figure, we see that the particle is most likely at the middle of the box, while it definitely will not be at the boundaries of the box (as the bottom of the box is equal to zero). Likewise, for n = 2, the particle will most likely be in the middle of the two halves of the box, and not at the centre or the boundaries of the box.

Figure 2

The wave function(s) for an electron in a box



Note. The probability distribution of the particle is squared, hence is always nonnegative, while the wave function itself can be negative (LibreTexts, n.d.).

There is more to say about the formalism and interpretation of quantum mechanics, but the above will suffice. Let us focus on the Schrödinger equation, which tells us how wave functions evolve. For example, the time-independent Schrödinger equation (TISE) tells us how a wave function evolves across space, irrespective of time. TISE, along with all other versions of the Schrödinger equation, is a continuous, nonrelativistic function. Some argue that quantum mechanics is incomplete because it is discontinuous at the point of a wave function collapse. What is the wave function collapse? Formally, it is the reduction of a wave function to a single eigenstate, when previously, it was a linear combination of multiple eigenstates. That is, suppose we have an electron that can either be in a spin up state or a spin down state. Pre-measurement, this electron is in a superposition state, i.e. it is both in a spin up and spin down state. Upon measurement, the wave function collapses. Suppose we measure the electron to be in a spin up state. The wave function must reflect that. Hence, we eliminate the down state component, and renormalise it (since the square modulus amplitudes of each component must sum to unity).

1. $\psi_A = 1/\sqrt{2}\,|\uparrow\rangle - 1/\sqrt{2}\,|\downarrow\rangle$ (Superposition of both up and down)

2. $\psi_A = |\uparrow\rangle$ (Post-measurement; Definite down state)

   (This is an oversimplification, but it will suffice)

Therein lies the problem. This process is not continuous in relation to the Schrödinger equation. The Schrödinger equation itself does not contain, nor characterise this collapse process. Thus, the Schrödinger equation alone does not describe the behaviour of an electron in full. Consider the following:

3. Quantum mechanics is complete.
4. The Schrödinger equation describes the evolution of particles in full.
5. The wave function collapse describes a discontinuous process.

(3.), (4.) and (5.) together are mutually inconsistent. Completeness means that all the relevant physical properties and dynamics of a particle are provided by a theory. Incompleteness, in this case, means that a particle's behaviour is not precisely provided by the Schrödinger equation, or by the theory at large. Without the collapse postulate, we would not have wave functions which correspond to the physical states of particles. Without the Schrödinger equation, we would need an alternative description of the evolution of particles. Are there alternative descriptions? Before we consider them, let us first consider a natural response to (3.)-(5.).

6. Quantum mechanics is complete.
7. The Schrödinger equation describes the partial, continuous evolution of a particle.
   7.1. The Schrödinger equation does not describe the evolution of particles in full.
8. The wave function collapse describes a discontinuous process of the evolution of particles.

One might argue that (3.)-(5.) is not problematic as it can be explained away by (6.)-(8.), with the compromise of (7.1.). Thus, one argues that there is an underlying premise of (3.)-(5.): the desire for one continuous function which governs the evolution of particles. Even if we do away with this desire, there are still tensions to resolve. (7.) is problematic at "the partial, continuous evolution of a particle". The problem is that we expect particles to behave in a manner which is isomorphic to some continuous function, under some framework. That is, we expect particles to not have any abrupt behaviours, such as going from indefinite states to definite states. But this is exactly what we observe, when we measure a particle in a superposition. Thus, one could argue there is nothing wrong with the Schrödinger equation per se. We just need to find something that characterises this indefinite to definite behaviour. One alternative candidate is the Dirac equation, a relativistic counterpart. Suppose we replace the Schrödinger equation with the Dirac equation in (7.) and (7.1.). We have reasons to consider the Dirac equation. It is relativistic. This compatibility with special relativity is desirable as all physical theories aim to describe the world around us. It would be strange for us to have different theories of the same subject-matter not agree with each other. However, we obtain similar conclusions, and problems. The problem is that whichever continuous function we choose, we get similar, dissatisfying results. Adapting Maudlin's (1995) 1.A, 1.B, and 1.C, it is clear to see what exactly is dissatisfying (p. 7).

9. Quantum mechanics provides a complete description of the behaviour of fundamental particles.
10. Elementary particles behave in a non-abrupt, "continuous" manner.
11. There exists a function that governs the evolution of a wave function.
12. The wave function collapse is the abrupt behaviour of elementary particles, which occurs on measurement.

(9.), (10.), (11.), and (12.) together are mutually inconsistent. This is the source of our philosophical dissatisfaction. We believe that (11.) is true, given the empirical success of quantum mechanics. We believe that our mathematical tools describe the world because it has been so successful thus far. But this effectiveness is not necessarily true. Perhaps it simply ends at quantum mechanics. What reason could there be for it to be ineffective in the quantum domain? As Maudlin (2019) says, there is nothing wrong with quantum mechanics proving novel results, and problems (p. 89). Even if we disregard the effectiveness of mathematics, the same problem persists: the abrupt behaviour of particles upon measurement. Contrary to (10.), particles behave in a "non-continuous" manner, and we do not know why. All explanations thus far have been ad hoc. No insights about the natural world have been generated; only questions have been specified. (12.) is forced upon us, given our observations and measurements. If we were to reject (12.), we would no longer have a subject-matter to talk about. Thus, if we reject (12.), we must reject (10.), along with all our knowledge and beliefs generated about quantum phenomena. Thus, a reasonable conclusion is that the abrupt behaviour of particles upon measurement is fundamental. A consequence of this is the negation of (9.): quantum mechanics is not complete.

Some have attempted to make sense of this incompleteness. They argue that consciousness plays a key role in the preservation of the "continuous-ness" property that we so desire. One version of this argument is as follows; in regards to (12.), Bell (1990) defines two types of jumps: Dirac jumps and LL jumps (short for Landau and Lifshitz; p. 22). A Dirac jump is a "forced jump of a quantum system as a result of a "measurement", an external intervention". An LL jump is the "spontaneous jump of a macroscopic system into a definite macroscopic configuration". A problem with these definitions is that it is not a technical definition. That is, it is non rigorous. One could argue it is an implicit definition, but I fail to see how a crucial part of quantum mechanics could be so imprecise, given that everything hinges on this definition. These definitions do not give any physical description of how particles behave upon measurement. Another problem is that LL jumps presuppose the same abrupt behaviour observed on a particle level on macropic objects and systems. I argue this is problematic, as it overextends the domain of quantum mechanics from the microscopic to the macroscopic world. I am sceptical that we can assign wave functions to macroscopic objects, given that such objects do not exhibit quantum properties, e.g. superpositions. Furthermore, wave functions are suggested as descriptors of particles because of de Broglie's matter wave equation. The equation asserts that macroscopic objects have matter waves. This is at odds with the lack of macroscopic quantum properties. Since LL jumps are instances of quantum properties, more must be said about LL jumps.

This is where quantum solipsism makes itself known. Solipsists argue that there exists a different type of measurement that does not physically interact with the system. They argue that LL jumps can be explained away. They pose a hypothetical; suppose we have an electron trapped in a box, with an energy state of n = 2. Suppose we put this box in a room with another person, named Alice. Suppose that outside this room is another person: Junpei. Under the LL jump framework, Junpei argues that both the electron and Alice are described by a wave function. However, Alice would disagree, as upon measurement, she would know what state the electron is in. Thus, Alice would argue that she is not in a superposition state. Wigner (1961) argues that the superposition wave function argument could be resolved if one argues that Junpei has a special status: the "privileged position as the ultimate observer" (p. 179). Wigner argues this as he recognises a relativity of sorts. Junpei believes that Alice is in a superposition because he is uncertain of the results of the measurement. However, Alice argues otherwise. Their disagreement is rooted in the difference of information each has, and the fact that both Alice and Junpei are conscious beings. One can only be an ultimate observer if one is conscious. Furthermore, it is not immediately apparent how we should assign the status of ultimate observation on people, if there is more than one candidate. Afterall, there is no relevant difference between Alice and Junpei. Thus, the logical conclusion that Wigner states has similar issues to LL jumps, as both assert that macroscopic objects have quantum properties. That said, Wigner argues that consciousness has a special feature, saying that "beings with a consciousness must have a different role in quantum mechanics than the inanimate measuring device" (p. 180). That is, if we replaced Alice with a traditional measuring device, the measuring device itself cannot be an "ultimate observer", given its lack of consciousness. Stated differently, it makes no sense for the traditional measuring device to assert that other observers are in macroscopic superposition states, if it replaced Alice. Thus, traditional measuring devices do not give rise to disagreements of reality. The problem here is that this disagreement seems to have no clear resolution.

There are many concerns about the consciousness approach. Once concern is about quantum consciousness. The brain itself is made of elementary particles, which exhibits quantum properties. If one is a materialist or a physicalist, one would need to say more about how a set of elementary particles can play a different role in quantum mechanics, compared to all other non-conscious-set of particles. If one is not a physicalist, one would need to provide an account of this novel quantum property of consciousness. Another concern is about the relation between wave functions and consciousness. Recall that LL jumps are rooted in macroscopic matter waves. If one were a physicalist, consciousness is similarly rooted in matter waves. Where does the status of ultimate observation arise from? What about consciousness preserves the continuity of wave functions? Recall that in Wigner's scenario, we assigned Junpei's status as the ultimate observer so that the scenario itself remains logically consistent. However, a tension remains: what is so special about Junpei that makes him the ultimate observer? There seems to be no relevant feature, just our desire for logical consistency. Furthermore, what exempts consciousness from LL jumping? Thus, I argue such consciousness arguments fail, as they only provide a continuous account of knowledge-that, and neglect knowledge-how. Solipsists argue that we have complete knowledge of the physical states and dynamics of particles. They argue that we know that the particle is either in a superposition state or not. We know when it collapses, and that it collapses. This "continuous" behaviour is preserved and grasped by us. But they neglect to elaborate on how continuity is preserved, apart from merely stating that it is. They also do not provide an account of the physical behaviour of particle collapse. Even if the knowledge-that of particles is continuous to us, they have not provided a detailed account of ultimate observation. An initial reaction is to claim that there is only one ultimate observer, but is that really the case? What if both Alice and Junpei are ultimate observers? We would obtain a relativity, similar to special relativity, with "frames of references" which track people's consciousness, e.g., frame 1 being Alice's perspective, frame 2 being Junpei's perspective. Would such an account succeed?

In principle, there is nothing wrong with asserting that consciousness has unique quantum properties. The problem is that it is currently unclear what precisely these quantum properties are, and what features give rise to these properties. One would need to develop a theory of quantum consciousness to justify such assertions, the same way people have been on a quest for a unified theory of physics, which combines general relativity with QFT. Otherwise, the only reasons we have to consider these postulates is in reference to the hard problem of consciousness, and a general appeal to the measurement problem.

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