

# The Role of the Observer in Interpretations of Quantum Mechanics

by

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## Introduction

Although quantum mechanics has significantly advanced our understanding of the physical world, it has also been a source of great confusion. Myriad interpretations, and interpretations of interpretations, have been proposed to try and explain away the seeming inconsistencies which lie at the heart of quantum mechanics. All of these attempts at interpretation center on the seemingly intractable measurement problem.

In this essay I argue that a number of interpretations of quantum mechanics are plagued by inadequate and misleading assumptions about the observer. These assumptions are based on a naïve "folk conception" of the observer. In discussing two phenomena studied in modern cognitive science, I will argue for a rejection of the naïve conception of the observer and adopt a more sophisticated view which offers a significant interpretational payoff. I argue that although the measurement problem in quantum mechanics appears to be a scientific problem requiring a scientific solution, it is plausible that the problem might be a pseudo-problem resulting from a conceptual confusion. The conceptual confusion is caused by naïve assumptions about the nature of the observer.<sup>1</sup> Based on these arguments I will reevaluate a number of interpretations and assess the role of philosophy in interpreting quantum mechanics.

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<sup>1</sup> Steve Gerrard, discussion with author, Williamstown, MA May 12 2005.

# Chapter I: Introduction to Quantum Mechanics

## *1. Quantum Formalism*

A quantum state is a formal description of the properties of a quantum system. An example of a simple quantum variable is the spin of an electron (momentum, position, and energy are a few others). Electrons are spin  $\frac{1}{2}$  particles, which means that in each direction, x, y, or z, the electron can possess a spin either up or down.

This simple quantum state describes the outcome probabilities of a measurement of an electron's spin in a certain direction. We can express this quantum state in a formal way using Dirac notation as  $\frac{1}{\sqrt{2}}|+\rangle_z + \frac{1}{\sqrt{2}}|-\rangle_z$ , where the symbol  $|+\rangle_z$  represents spin-up along the z-axis, and  $|-\rangle_z$  represents spin-down along the z-axis. The probabilities of each outcome are represented by the coefficients outside the spin-up and down symbols. The outcome probability is the magnitude squared of the coefficient. This formal expression is the same as saying we predict that a measurement of an electron in this state will yield spin-up along the z-axis half of the time, and spin-down along the z-axis half of the time.

Experimentally, this description of electron spin is highly effective. However, what sense can we make of this description? How can we *interpret* it? One possible interpretation would claim that the probabilities arise from the experiment revealing the relative frequency with which members of a large group of systems, all prepared in the

same way, *possess particular values of the quantity being measured, prior to the experiment*. This interpretation can be shown to be incorrect. We will refer to it as the naïve interpretation. The problem with this interpretation lies in the attribution of quantities *prior* to the measurement. In other words, it is incorrect to assume that 50% of electrons have spin-up along the z-axis before they are measured. A more accurate interpretation would state that when we make an observation, 50% is the frequency with which we will observe the given spin quantity. On the surface this seems like a trivial distinction, and one might reply with the claim that a chair is a chair, it will have a definite height and it has that height before and after we measure it. Similarly, spin is a physical observable and it does not change with our measurement. However intuitively appealing this argument may be, in the case of quantum phenomena this is not how things work.

The only description we can give of the spin of the electron prior to measurement is its quantum state:  $\frac{1}{\sqrt{2}}|+\rangle_z + \frac{1}{\sqrt{2}}|-\rangle_z$ . We describe this state as a *superposition* of spin-up and spin-down. In ordinary language, being in a superposition means that the electron could have spin-up or spin-down when we measure it, but it does not yet have a definite spin and will only possess a definite spin when a measurement is made.

It is possible, with an apparatus known as a Stern-Gerlach magnet, to physically separate electrons according to their spin along a given axis. We begin with a Stern-Gerlach magnet aligned along the z-axis. When we send electrons in the quantum state  $\frac{1}{\sqrt{2}}|+\rangle_z + \frac{1}{\sqrt{2}}|-\rangle_z$  into the magnet, half of the electrons will come out the spin-down channel and the other half will come out the spin-up channel. Following this measurement we have two separate groups of electrons in the quantum states

$|+\rangle_z$  and  $|-\rangle_z$ . Now suppose we take only the  $|+\rangle_z$  (spin-up electrons) and run them through another magnet, this time measuring their spin along the x-axis. We should note that the quantum state  $|+\rangle_z$  can be expressed with respect to spin along the x-axis as

$$|+\rangle_x + \frac{1}{\sqrt{2}}|-\rangle_x.$$

We would be correct in predicting that we would observe half of the electrons coming out the spin-up channel, and the other half out the spin-down channel.

Up to this point we have two Stern-Gerlach magnets in a row, the first separating out electrons according to spin along the z-axis, and the second along the x-axis. Recall that we only send the group of electrons with spin-up in the z direction on through the second Stern-Gerlach magnet. What we do next is place a third Stern-Gerlach magnet in the series, this time oriented once again to measure spin along the z-axis. Furthermore, we will only send the group of electrons that came out of the spin-up channel on the second magnet through our third magnet. Keep in mind that the group of electrons with spin-up along the z-axis has already been divided into two new groups and one of them is going through another Stern-Gerlach magnet oriented along the z-axis.

What are the possible outcomes of this final measurement? If our naïve interpreter is correct in saying that the quantities of spin are possessed prior to the measurement, then we might claim that all of the electrons would come out through the final spin-up channel since they have always possessed the intrinsic quality of spin-up along the z-axis. Quantum mechanics predicts a different outcome. According to the formalism, the electrons exiting the second magnet are in the quantum state  $|+\rangle_x$  which can be expressed

along the z-axis as  $\frac{1}{\sqrt{2}}|+\rangle_z + \frac{1}{\sqrt{2}}|-\rangle_z$ . Therefore, half of the electrons will emerge from the spin-up channel and half will emerge from the spin-down channel. This is exactly what happens.

A proponent of the naïve interpretation would argue that the act of passing the electrons through the second magnet somehow changed the preexisting value of spin along the z-axis. This hypothesis can be easily disproved. If instead of sending only the spin-up electrons, we send all of the electrons emerging from the second magnet through the third magnet, all the electrons will exit the third magnet through the spin-up channel. This shows that what changes the value of spin along the z-axis is not the physical event of passing through the second magnet.

## ***2. The Measurement Problem***

Why do the outcomes of measuring spin along the z-axis change between the first and third Stern-Gerlach magnets? This question directs us towards one of the deepest issues in quantum mechanics: the measurement problem. Prior to performing a measurement on a quantum state in a superposition we have seen that it is not possible to ascribe an intrinsic value of spin to a given particle. Only after a measurement is made can we talk of specific values. To better understand this concept we can think of a measurement as the interaction between the quantum particle and the classical measuring apparatus. According to this view, a distinction is made between the quantum system being measured and the apparatus which is doing the measuring. This divides the world of our experiment (W) into two parts: the system (S) and the apparatus (M), where

$W=S+M$ . However, there is no reason why we can't think of a classical apparatus as a large quantum system made up of many quantum particles. Recall our experiment to test the spin of an electron through a Stern-Gerlach magnet. Outside of the two channels of the magnet we have detectors which are connected to a dial which can point to three possible positions: "spin-up," "spin-down," and "ready." Before the electron is run through the apparatus the dial is centered on "ready." Once we run the electron through the apparatus we will observe the dial to be pointing either to "spin-up" or "spin-down." The problem with our division between S and M is that we can also think of the dial as a quantum system of many molecules. For that matter, we can think of any part of the measuring apparatus as part of S. Where does the world of S end and M begin? At the core of these explanations is a struggle to gain a clear understanding of what it means to make a measurement, and what causes the transition from an unobservable superposition, to a real observable. This is the heart of what is known as the measurement problem in quantum mechanics.

Another striking example of the problems which arise from quantum mechanics' ambiguity with regards to measurement is the Schrodinger's Cat thought experiment. Imagine that we have a box which is completely closed off to the outside world. Inside the box is a cat with a gun to its head. We also have a measuring apparatus much like in the previous example, except the dial is connected to the gun. If the dial goes to "spin-up" the gun fires, if it goes to "spin-down" the gun does not fire. If we view the dial as a quantum system and claim that a measurement is not made until the box is opened we must say, according to quantum mechanics, that the cat is in a superposition between life and death. The possibility of the cat being neither alive nor dead seems to violate every

principle of our basic understanding. Therefore, we might be inclined to say that a measurement has taken place inside the box and that the cat exists in a definite state of life or death.

Quantum mechanics requires us to make the deeply unsettling claim that the cat is in a state which can be described as neither alive nor dead. In trying to resolve this issue we are faced with three choices. The first choice is to reject quantum mechanics on the grounds that it forces us to accept claims such as the cat is neither alive nor dead. Since quantum mechanics is a powerful theory with regards to predicting physical phenomena this choice is unappealing. Another option is to accept that the cat is neither alive nor dead. This means we admit that we are unable to give a clear description of the cat's state prior to looking in the box. By accepting this choice we claim that Schrodinger's Cat does not present a problem, but an example of limitations of what we can know about the cat prior to measurement. The final choice is to retain the theory of quantum mechanics and try to reinterpret, supplement or change it so that we are not forced to claim that the cat is in a superposition of life and death.<sup>2</sup>

### ***3. Accurate Picture of Physics***

Before going any further it is important to ensure that we are working with an accurate picture of physics. Part of the aim of this essay is to dispel the notion that physics is "a concrete floor of established, precise facts about simple concepts of matter

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<sup>2</sup>Bojana Mladenovic, discussion with author, Williamstown, MA May 11 2005.

and motion.”<sup>3</sup> This naïve way of thinking about the physical world, passed down from the age of Descartes and Newton, could easily deceive us into thinking that everything that happens in the world is easily explainable by physics. This is not entirely true. Issues at the heart of physics, such as the measurement problem, illustrate the range of uncertainties we face when it comes to the "facts" of physics. Moreover, the descriptions of physical phenomena provided by quantum mechanics are not the same as the deterministic descriptions provided by Newtonian physics.

#### ***4. Interpretations***

Although there is general agreement on the validity of experiments illustrating quantum behavior, opinions diverge, often dramatically, on the issue of interpretation. The point is that while there are many different interpretations offering vastly different explanations of physical events, they are all in some way bound by empirical evidence. Furthermore, at the heart of most interpretations is a desire to make sense of the seemingly intractable measurement problem. I will devote the rest of this chapter to a brief exposition of four significant attempts to give a coherent and complete interpretation of quantum phenomena.

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<sup>3</sup> Jeremy Butterfield, "Quantum Curiosities of Psychophysics," *PhilSci Archive*, March 9, 2001, 21, <http://philsci-archive.pitt.edu/archive/00000193>.

#### 4.1 *The Copenhagen Interpretation*

One explanation for the measurement problem comes from the Copenhagen Interpretation. Proponents of the Copenhagen Interpretation point out that quantum mechanics is very accurate in its predictions. The most we can say about the definite qualities of an electron is that after the electron passes through the Stern-Gerlach magnet the quantum state is either "spin-up" or "spin-down."

The Copenhagen Interpretation makes a clear distinction between the classical world and the quantum world. Rather than abandoning classical mechanics as the large-scale limit of quantum mechanics, classical mechanics is treated as a necessary backdrop for all scientific understanding. Niels Bohr, the main contributor to this interpretation, believed that classical concepts, such as determinate positions, are necessary for any description of physical experience. This means that the "Copenhagen Interpretation is first and foremost a semantic and epistemological reading of quantum mechanics."<sup>4</sup> The interpretation is semantic because it claims there are boundaries to our meaningful description of the physical system. This is because we can only meaningfully describe the particle as being in a specific state by employing classical concepts. Since classical concepts are only applicable to particles after a measurement is made, there is no meaningful ontological description which can be given prior to measurement. The interpretation is epistemological because any description of the system prior to measurement is purely a statistical representation of the information we have about the possible states of the particle. The position that quantum mechanics offers a purely

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<sup>4</sup> Jan Faye, "Copenhagen Interpretation of Quantum Mechanics," *Stanford Encyclopedia of Philosophy*, <http://plato.stanford.edu/entries/qm-copenhagen>.

statistical representation of what we know about the particle implies that we should resist the temptation to extrapolate deeper conclusions about the quantum world beyond probabilities. Due to the limitations on the use of our classical concepts, *an ontological description of quantum events prior to measurement is impossible*. This contrasts with the approach taken by the Bohm Theory, which I will discuss later, which attempts to provide an ontological interpretation of the wavefunction.

#### *4.2 Problems with Copenhagen*

According to the Copenhagen interpretation, a measurement leads to a violation of the Schrodinger equation. The Schrodinger equation is the basic equation from which we derive the wavefunction and basic information about the physical characteristics (i.e. energy and position) of a quantum system. The wavefunction is a probabilistic distribution of a quantum particle's possible positions. The wavefunction obeys the Schrodinger equation until a measurement is made. At this point an event known as the "collapse of the wavefunction" occurs, and the wavefunction no longer follows Schrodinger's equation. The wavefunction collapses to a single point after a measurement of position, because the position is known. This further emphasizes the way in which quantum mechanics is lacking in its description of measurement, since there is no formalism which can express the collapse of the wavefunction. The wavefunction collapse forces the supporters of the Copenhagen interpretation to make an ad-hoc revision to quantum mechanics' wave dynamics and assert that there are two dynamic processes a quantum system may undergo: the first is continuous evolution according to

Schrodinger's equation, and the second is discontinuous collapse due to a measurement. However, the discontinuous collapse is not a devastating problem. Since the Copenhagen Interpretation is merely epistemological, the wavefunction represents our information about the system, not the system itself. Therefore, when the wavefunction collapses there is no discontinuous change in the physical system, but rather a discontinuous change in our information about the system. In this sense, the collapse of the wavefunction is merely a symbolic event. Nevertheless, there is a troubling lack of consistency in the formalism of quantum mechanics caused by the act of measurement.

Many physicists are deeply unsatisfied by Copenhagen's claim that an ontological description of quantum phenomena is impossible. To some physicists the measurement problem was too significant to ignore and the lack of ontological description left quantum mechanics incomplete. In particular, Albert Einstein tried very hard to show that quantum mechanics is incomplete. Along with Boris Podolsky and Nathan Rosen, Einstein wrote a famous paper<sup>5</sup> which argued that either quantum mechanics is incomplete or we must abandon locality. Another reason that physicists believed Copenhagen's version of quantum mechanics to be incomplete is that "the task of quantizing general relativity raises serious questions about the meaning of the present formulation and interpretation of quantum mechanics when applied to so fundamental a structure as the space-time geometry itself."<sup>6</sup> In other words, there is difficulty finding a suitable way to unify relativity and the present formulation of quantum mechanics.

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<sup>5</sup> Albert Einstein, Boris Podolsky and Nathan Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 47, (1935): 777-780.

<sup>6</sup> Hugh Everett III "'Relative State' Formulation of Quantum Mechanics," *Reviews of Modern Physics* 29, no. 3 (1957): 454.

Physicists such as David Bohm have proposed ontological interpretations of quantum mechanics in the hopes of solving some of the problems of quantum mechanics. I do not want to make the claim that a scientific theory without an ontological description is incomplete. However, I believe that in the case of quantum mechanics an ontological interpretation might provide a solution to the seeming incompatibility with relativity and help us better understand why the formalism breaks down during a measurement. Therefore, if we could find a way of solving these problems through an ontological interpretation, Copenhagen's philosophical position that further interpretation is impossible might be unjustified.

#### *4.3 Bohm's **Hidden Variable** Theory*

The second interpretation I want to discuss is Bohm's Hidden Variable Theory.<sup>7</sup> Bohm's theory aims to provide an ontological interpretation of the wavefunction. Instead of treating the wavefunction as a probabilistic distribution (as Copenhagen does), the wavefunction is given the status of "quantum potential," which can be thought of as being similar to currents in a river. In formulating this theory Bohm also makes the claim that all quantum particles have a definite position at all times, even before a measurement. This assumption marks a radical departure from the Copenhagen Interpretation, which denies the ascription of definite positions prior to measurement. From the exact position of the particle and the 'quantum potential' we gain a classical picture of quantum dynamics, where particles have definite trajectories. The problem is

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<sup>7</sup> Although a number of Hidden Variable Theories have been developed, David Bohm's is the most well known.

that some of the information necessary for us to predict a particle's trajectory is hidden, thus the name of the theory.

With this classical picture of quantum behavior we can employ Newton's second law of motion, differing only in the addition of the quantum potential. In a similar fashion to gravity or magnetism, the forces associated with the quantum potential influence particles to follow certain paths. In the context of electron spin, if an electron is in a superposition of spin along the z-axis and it goes through a Stern-Gerlach measuring apparatus aligned along the z-axis, the quantum potential associated with each spin state in the superposition can be thought of as a current which works to push the particle towards its respective channel in the apparatus. The determinate position of the particle prior to measurement demands that the particle exists in a distinct region of the quantum potential where its position will determine the path it takes through the 'currents' of the quantum potential.

Another benefit of Bohm's theory is that it solves the measurement problem. There is no "collapse of the wavefunction" since the wavefunction is only one part of the entire picture. A quantum measurement of position is no different than a classical measurement of position. In classical mechanics we describe the trajectory of a ball being thrown (the difference in the Bohm Theory is that we are unable to know the trajectory because some of the necessary information is hidden). Before we observe the ball, we know its location based on the trajectory. Therefore, our description of the ball before measurement is completely in agreement with our observations. With a quantum particle we know there must be a definite trajectory. Since prior to measurement the particle has a determinate position, there is no need to establish where along the measurement chain the

shift from indeterminate to determinate occurs because it never happens. Therefore, the problem of measurement never arises in the first place.<sup>8</sup>

#### 4.4 Problems with Bohm

One problematic implication of Bohm's Theory is that if we physically flip the measuring apparatus, the deterministic outcome for a measurement instantly changes. This is because the quantum potential will guide the particle through the same channel regardless of the orientation of the measurement device. Therefore, we are forced to accept that there are only a handful of "real" quantities of a quantum particle, such as position and velocity. Quantities such as spin become arbitrary since changing the measurement apparatus changes the spin value.

Another serious problem with Bohm's theory is that it leads to a violation of locality. The principle of locality states that "elements of reality pertaining to one system cannot be affected by measurements performed 'at a distance' on another system."<sup>9</sup> This violation occurs when two particles share the same nonseparable wavefunction and we maintain that these two particles have determinate values of position and velocity. In an experiment led Alain Aspect it was shown that it would be impossible for these particles to have determinate values prior to measurement unless they could somehow exert an influence on each other faster than the speed of light.<sup>10</sup>

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<sup>8</sup> The view that Bohm's Theory solves the measurement problem is not universally accepted. Abraham Stone argues that the violation of locality in the Bohm Theory is actually a deeper version of the measurement problem. Abraham Stone "Does the Bohm Theory Solve the Measurement Problem?" *Philosophy of Science*, 61, no. 2 (1994): 250-266, <http://www.jstor.org>.

<sup>9</sup> Michael Redhead, *Incompleteness, Non-Locality and Realism* (Oxford: Clarendon Press, 1987), 74.

<sup>10</sup> For a discussion of the experiment and its implications see J.S. Bell, *Speakable and Unspeakable in Quantum Mechanics* (Cambridge: Cambridge University Press, 2004).

#### 4.5 *The Everett Interpretation*

The next interpretation I wish to discuss is known as the Everett interpretation, named after Hugh Everett III, who first expounded the theory in 1957 in his doctoral dissertation. A desire to find a practical solution to the measurement problem within the formalism of quantum mechanics was the central motivation for Everett's "relative state" formulation of quantum mechanics. The goal of Everett's formulation is to "deduce empirical predictions of the standard theory [of quantum mechanics] as the subjective experiences of observers who are themselves treated as physical systems" in order to include the entire physical universe in the wavefunction.<sup>11</sup>

Everett saw the measurement problem as a logical inconsistency arising from problems with the basic equations of quantum mechanics. The problems become apparent when considering the case of the closed universe, where there are no external observers. In this situation we are unable to account for the dynamical events of standard quantum mechanics since there is no external observer to induce the collapse of the wavefunction. Remember that under the standard formulation there are two permissible types of dynamical evolution of the wavefunction: the first is the discontinuous change brought about by the observation of a quantity (process 1), and the second is the "continuous, deterministic change of state of an isolated system with time according to Schrödinger's equation" (process 2).<sup>12</sup>

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<sup>11</sup> Jeffrey Barrett, "Everett's Relative-State Formulation of Quantum Mechanics," *Stanford Encyclopedia of Philosophy*, <http://plato.stanford.edu/entries/qm-everett>.

<sup>12</sup> Everett, 454

Process 2 can be understood as the normal changes of a wavefunction over time. Process 1 is the collapse of the wavefunction caused by a measurement. In the case of a measurement of a spin  $z$  particle we can think of process 1 as represented by the change from the superposition  $\frac{1}{\sqrt{2}}|+\rangle_z + \frac{1}{\sqrt{2}}|-\rangle_z$ , into the determinate state  $|+\rangle_z$  or  $|-\rangle_z$ . It is important to understand that an event described by process 1 occurs only when an *external observer* makes a measurement on the system. Therefore the problem, according to Everett, is that

Not all conceivable situations fit the framework of this [traditional quantum mechanics] mathematical formulation. Consider for example an isolated system consisting of an observer or measuring apparatus, plus an object system. Can the change with time of the state of the *total* system be described by process 2? If so, then it would appear that no discontinuous probabilistic process like process 1 can take place. If not, we are forced to admit that systems which contain observers are not subject to the same kind of quantum-mechanical description as we admit for all other physical systems.<sup>13</sup>

Basically, we must always have an external observer functioning outside the laws of quantum mechanics in order to induce process 1 dynamics. This means that it is impossible for quantum mechanics to provide a description of the entire universe of physical systems and observers since we would always need an observer external to the system. Everett saw this as a serious problem because this limited our ability to describe the physical universe. Everett believed that quantum mechanics should be able to give a description of the entire universe, including observers. By including the entire universe in

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<sup>13</sup> Ibid., 454

the wavefunction we could give a quantum mechanical description of the big bang. Also, this new formulation might be "suitable for application to general relativity."<sup>14</sup>

Everett proposed a two-part solution to this problem. His first step is to completely drop process 1 from his formulation. This enables him to include the measurement apparatus and observer as part of the wavefunction. His next step is to formally develop a method of including the observer as part of the wavefunction, so that he has a description of measurement which falls under process 2.<sup>15</sup> Everett claims that the jump from superposition to specific outcome is an illusion, "so far as the complete theory is concerned all elements of the superposition exist simultaneously and the entire process is quite continuous."<sup>16</sup> This means that process 1 dynamics are nothing more than an illusion caused by the subjective perspective of the observer.<sup>17</sup> According to this interpretation, instead of collapsing after an observation the wavefunction branches into a new wavefunction with the observer included inside. Formerly, we expressed a measurement as a transition from  $\frac{1}{\sqrt{2}}|+\rangle + \frac{1}{\sqrt{2}}|-\rangle_z$  to either  $|+\rangle$  or  $|-\rangle$ . Now a measurement is the transition from  $\frac{1}{\sqrt{2}}|+\rangle + \frac{1}{\sqrt{2}}|-\rangle$  to:

$$\frac{1}{\sqrt{2}}|\text{Observer spin-up, }+\rangle + \frac{1}{\sqrt{2}}|\text{Observer spin-down, }-\rangle_z.$$

This implies that there are two representations of the same observer in the wavefunction. In a certain sense, the observer branches into two different states. However, the observer is only aware of one of these states.

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<sup>14</sup> Ibid.

<sup>15</sup> Ibid., 456

<sup>16</sup> Ibid., 457

<sup>17</sup> Ibid., 459

There are many benefits to the Everett Interpretation. Formally, it is an elegant interpretation which requires no ad-hoc inventions such as quantum potentials or postulating wavefunction collapse. In addition, all of the basic principles of quantum mechanics, such as the uncertainty principle, remain intact.

#### *4.6 Problems with Everett*

Everett is often criticized as not filling out the details of his theory. The theory appears incomplete due to its inability to account for the existence of a single determinate record of measurement.<sup>18</sup> The result of an observation on a quantum system is no longer a collapse of the wavefunction into a specific measurement outcome, but rather a branching of the observer into a series of different states.<sup>19</sup> If the observer branches into two different observers each measurement, how do we explain that there is a determinate report of observation? In other words, there is no way of understanding why we see a determinate outcome when we make a measurement, since the wavefunction seems to say that the observer measures all possible outcomes simultaneously. It appears as though abandoning process 1 dynamics restricts our ability to explain determinate outcomes of observation. Everett, however, believes that this is not a serious threat to his theory:

Some correspondents have raised the question of the "transition from possible to actual," arguing that in "reality" there is—as our experience testifies—no such splitting of observer states, so that only one branch can ever actually exist.

The whole issue of transition from "possible" to "actual" is taken care of in the theory in a very simple way—there is no such transition, nor is such

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<sup>18</sup> Jeffrey Barrett, "Everett's Relative-State Formulation of Quantum Mechanics," *Stanford Encyclopedia of Philosophy*, <http://plato.stanford.edu/entries/qm-everett>.

<sup>19</sup> Everett, 459

a transition necessary for the theory to be in accord with our experience. From the viewpoint of the theory *all* elements of a superposition (all "branches") are "actual," none any more "real" than the rest. It is unnecessary to suppose that all but one are somehow destroyed, since all the separate elements of a superposition individually obey the wave equation [Schrodinger's equation] with complete indifference to the presence or absence ("actuality" or not) of any other elements. This total lack of effect on one branch on another also implies that no observer will ever be aware of any "splitting" process.<sup>20</sup>

Whether or not this is a satisfactory response remains to be seen. Following my analysis of the observer, I will return to the issue of being aware of the splitting process.

#### *4.7 The Many Minds Interpretation*

Many find the original version of the Everett Interpretation to be fundamentally unsatisfying in its inability to explain why the observer remains in a superposition after a measurement even though we see only one outcome. This has led some to claim that "the interpretation itself needs interpreting."<sup>21</sup> In response, a number of interpretations of the Everett Interpretation have been proposed. I wish to focus on that offered by David Albert and Barry Loewer, known as the Many Minds Interpretation. Even though it aims to revise the Everett Interpretation, The Many Minds is an interpretation in its own right. However, for the purposes of this essay I will only focus on certain arguments made by Albert and Loewer about the role of the observer.

According to Albert and Loewer, the fundamental problem with Everett's original formulation is the assertion that "macroscopic measuring devices and observers

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<sup>20</sup> Ibid., footnote 459-460

<sup>21</sup> David Albert and Barry Loewer "Interpreting the Many Worlds Interpretation," *Synthese* 77 (1988): 198

themselves can be in superpositions."<sup>22</sup> In their paper titled "Interpreting the Many Worlds Interpretation," Albert and Loewer argue that if we accept the following three principles we are led to a fundamental contradiction which necessitates the adoption of "non-physicalism."

(i) A is an observer who can perfectly measure x-spin. (That is: subsequent to an x-spin measurement by M  $|+\rangle_x$  iff M believes that  $|+\rangle_x$  and  $|-\rangle_x$  iff M believes that  $|-\rangle_x$ )<sup>23</sup>

(ii) A can correctly report some of her mental states. Specifically, when A sincerely reports that she has a definite belief about the value of x-spin (i.e. she reports: "It is either the case that I believe that spin is up or it is the case that I believe that spin is down, but it is not the case that my beliefs about the value of x-spin are in any way uncertain, or ill-defined, or superposed"), then A does believe that the x-spin has a definite value.

(iii) The state wherein A believes that  $|+\rangle_x$  and the state wherein A believes that  $|-\rangle_x$  are identical with certain physical states of A's brain. We will call those states  $B|+\rangle_x$  and  $B|-\rangle_x$ .<sup>24</sup>

According to Albert and Loewer, the physicalist assumption (iii) leads to a contradiction. In the Everett Interpretation, when the observer reports a definite outcome this is merely a subjective statement, in actuality the wavefunction remains in a superposition. This means that the observer's physical brain states also remain in a superposition despite the fact that her verbal report is definite. Therefore we see a violation of the "physicalist" assumption that physical brain states correspond to reported mental states."<sup>25</sup> Based on this argument, Albert and Loewer find it reasonable to reject physicalism and postulate a

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<sup>22</sup> Ibid., 203

<sup>23</sup> Albert and Loewer use a different formal symbol for spin-up and spin-down; I changed them for the sake of clarity and consistency.

<sup>24</sup> Ibid., 204

<sup>25</sup> Ibid., 204-205

dualism. As I will argue in the third chapter, not only is claim (iii) false, but its rejection does not necessitate the acceptance of a "non-physicalism."

## Chapter II: Assumptions about the Observer

### *1. Quantum Mechanics and the Observer*

From a brief survey of four different interpretations it should be evident that the nature of measurement is a central issue in quantum mechanics. Furthermore, the difficulty of clearly delineating the act of measurement has brought the measurement problem to the forefront of discourse on quantum mechanics. In my view, this difficulty is due in part to the way quantum mechanics has challenged our naïve assumption that measurement and observation grant us access to an observer-independent reality. In quantum mechanics, as opposed to classical mechanics, measurement significantly alters the physical system. In other words, when we make a measurement we change the system in a non-trivial way. The Heisenberg Microscope thought experiment — from which we can derive the celebrated uncertainty relations — formalizes this idea. Imagine a microscope designed to accurately measure an electron's position. We will discover that we can never measure the position with complete certainty, for in order to see the electron in the microscope we would have to bounce a photon off of it. This causes a transfer of momentum from the photon to the electron and slightly alters the electron's position. Through this thought experiment we see that our observations do not simply measure the system, but interfere with the system in a way that impacts our observations.

Few physical theories are explicit in their definitions of the observer (The Everett Interpretation is a notable exception). This is regrettable since the manner in which a theory describes the act of observation often has unnoticed philosophical suppositions.

Although I am not proposing an exhaustive definition of observation, for the purposes of this essay, I want to emphasize that a crucial aspect of observation is the direction of attention towards a specific stimulus.

A central argument of this essay is that naive assumptions about the observer have infiltrated interpretations of quantum mechanics. Furthermore, an analysis of these assumptions can be brought to bear on our understanding and acceptance of different interpretations. Ever since Kant argued for the *apriori* intuitions and categories which structure our conscious experience, we have had an account of the mind which rules out the possibility of truly unmediated access to the external world. In general, our modern conception of the mind accepts the idea that the mind mediates experience. Nevertheless, there are certain naïve "folk concepts" of the mind which are implicit in the way we talk about the act of observation. These naïve views are at work in a number of interpretations of quantum mechanics. Similar to the way in which we abandoned our conception of physics as a "concrete floor," we must strive to do away with our naive conception of the observer. However, abandoning these naive assumptions is a difficult task since they are not always immediately apparent. This assessment of the problem is analogous to the way Ludwig Wittgenstein saw the Augustinian picture of language in the *Philosophical Investigations*: "*A picture held us captive. And we could not get outside it, for it lay in our language and language seemed to repeat it to us inexorably.*"<sup>26</sup>

The naïve view of mind is not a coherent theory; it is simply an amalgamation of unjustified assumptions. The main naive assumption I will address in this essay is the claim that *the mind provides unmediated information about the external world through observation*. In this chapter I draw on experiments from cognitive science to argue that

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<sup>26</sup> Ludwig Wittgenstein, *Philosophical Investigations* (Oxford: Blackwell, 2001), 41<sup>e</sup>.

this assumption is incorrect. In the third chapter, I will explicitly show that these assumptions influence a number of interpretations of quantum mechanics. By exposing these assumptions I aim to find new ways of critically evaluating these interpretations.

### *1.1 Rejecting Assumptions: Binocular Rivalry*

Research into "binocular rivalry" indicates that in some situations it is quite natural to have determinate observation of an indeterminate stimulus. Experiments in binocular rivalry involve the projection of different images into each eye of the subject.<sup>27</sup> One specific experiment involved projecting an image of vertical stripes into the left eye and horizontal stripes into the right eye. Instead of seeing some blurry crosshatching combining the two images, subjects report seeing either horizontal or vertical stripes in alternating sequence. The fact that the subject sees only one determinate image at a time is significant. Binocular rivalry provides a clear example of how there can be a disparity between reported observation and the physical world.

This example suggests a far more complex version of observation than our naïve assumption allows. It is trivial to make the point that we are unaware of certain things in our visual field. By choosing to focus on certain objects while ignoring others, we are selective in our observations. By looking at the cursor on the computer screen while I type, I am unaware of my hands on the keyboard, although they are within my visual field. However, binocular rivalry implies that we are not always aware of the selectivity of our observations. Subjects in the experiment do not choose to focus on a horizontal

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<sup>27</sup> Nancy Kanwisher, "Neural Events and Perceptual Awareness" *Cognition* 79, (2001): 91, <http://www.elsevier.com/locate/cognit>.

pattern instead of a vertical pattern; they are unaware of their minds performing this act of selectivity. This involuntary selectivity clearly contradicts the claim that the mind provides unmediated information about the external world through observation.

Admittedly, there are limits to the applicability of this example to quantum mechanics. In the binocular rivalry experiments the experimenter has a different perspective than the subject. From this perspective it is clear that there are two different patterns presented side by side. In observations of superpositions there is no second perspective. Nevertheless, it is reasonable to claim that we should not reject the possibility that the mind performs a similar act of selection with respect to superpositions.

### *1.2 Rejecting Assumptions: Attentional Blink*

There are many experimental variations, but basically the attentional blink experiment involves a subject being shown multiple strings of letters and numbers in a rapid serial visual presentation (RSVP). Each string is presented for the same amount of time. The strings of letters and numbers, such as "GRSDPKN," are random except for two target strings. The first target (T1) is either an odd or an even string of numbers, such as "2222222". The second target (T2) is a word. In an experiment conducted by Steven J. Luck et al. there were two different temporal gaps between the presentation of T1 and T2. If T2 is presented three items after T1, it is referred to as Lag 3 and if T2 is presented seven items after T1, it is referred to as Lag 7. After the strings have been presented, the subject is asked to give a forced-choice response to a question about T1 and a question about T2. The question about T1 is "was T1 even or odd." Subjects almost always give a

correct response to this question. However, it has been observed that there is a severe drop from Lag 3 to Lag 7 in the ability of subjects to correctly make a forced-choice response to the question concerning T2. This gap of attention, which T2 at Lag 3 falls into, is known as the attentional blink. What is interesting about this experiment is that there is evidence which suggests that although subjects are unable to correctly answer a question about T2 in Lag 3 there is a certain degree to which T2 has been cognitively processed and identified by the subject's brain.<sup>28</sup>

In the Luck experiment a context word was presented before the RSVP and the second forced-choice question asked if T2 was related or unrelated to the context word:

To test whether the attentional blink reflects a postperceptual impairment in processing, we recorded event-related potentials (ERPs) from normal young adults and measured the 'N400' peak, (a negative peak at 400ms poststimulus) which reflects the degree of mismatch between a word and a previously established semantic context. For example, a large N400 would be elicited by the last word of the sentence 'The man wore blue trousers and a green bucket', but not by the last word of the sentence 'The man wore blue trousers and a green shirt'... Thus the presence of N400 in our study would provide strong evidence that words presented during the attentional blink are fully identified, even though subjects cannot accurately report them.<sup>29</sup>

Indeed, even for Lag 3 trials a N400 amplitude was observed. This shows that the "dissociation between N400 amplitude and discrimination accuracy implies that many of the errors at lag 3 in the experimental condition occurred despite correct semantic analysis."<sup>30</sup> These results led researchers to conclude that we make analyses and identifications which we are not aware of to the extent that we can verbally report them.

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<sup>28</sup> Justin Feinstein et al. "From Sensory Processes to Conscious Perception," *Consciousness and Cognition* 13 (2004): 325, <http://www.elsevier.com/locate/concog>.

<sup>29</sup> Steven J. Luck et al. "Word Meanings Can be Accessed but not Reported During the Attentional Blink," *Nature* 383, (1996): 616.

<sup>30</sup> *Ibid.*, 617

Even though the subject directed his or her attention at the strings characters, the subject was unaware of any observation. The reason that the subject was unable to report an observation was not because the stimulus failed to reach the subjects brain. Indeed, the stimulus was processed and identified by the brain. This experiment suggests that although belief states (such as a belief that T2 matches the context word) are determinate, they report a brain state which is not determinate. This is because if belief states reported determinate brain states, the N400 peak would have been accompanied by a correct answer to the forced-choice question. This serves of an example of how determinate observations can arise from indeterminacies, in this case, indeterminate brain states.

## ***2. The Sophisticated Observer***

In this chapter I tried to build a strong case against the nai've assumption that the mind offers us unmediated access to the external world. From this discussion a new picture of what I will call the "sophisticated observer" emerges. There is a level of complexity to the mind of the observer which is incompatible with our nai've assumptions. From binocular rivalry and attentional blink there is evidence that even though we may direct our attention at certain external stimuli, our mind significantly limits our awareness of these stimuli.

In the next chapter I will show that even though we may claim that the naïve conception is wrong we might be unwittingly supporting it by adopting certain interpretational positions. In fact, it is plausible that by formulating the measurement problem we are malting nai've assumptions about the observer.

## Chapter III: Implications for Quantum Mechanics

### *I. Implications for Quantum Mechanics*

In this chapter I will show that the criticisms of the naïve assumption from the previous chapter have significant interpretational payoffs. I have already mentioned that it is plausible that the measurement problem turns out to be a pseudo-problem caused by our naïve assumptions. I will argue that this possibility provides a basis for developing new criticisms of Bohm's Hidden Variable Theory. The Many Minds Interpretation also appears to make conclusions based on naïve assumptions. Superficially, rejecting our naïve assumptions seems to be detrimental to the Everett Interpretation. However, on a closer examination it becomes apparent that the Everett Interpretation offers a convenient framework for incorporating a more sophisticated conception of the observer. However, I want to make it clear that Everett never intended for arguments from cognitive science to be brought to bear on his interpretation. When discussing the problem of the observer's role in inducing the collapse of the wavefunction, Everett stated that "the question cannot be ruled out as lying in the domain of psychology."<sup>31</sup>

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<sup>31</sup> Everett, 454

### *1.1 Implications for Quantum Mechanics: Is Measurement a Problem?*

In the midst of all this confusion, one claim that is consistently made with certainty is that things *appear* to be definite. When we look at the dial of a measuring apparatus we report the dial to be in a definite position. If we accept the naïve assumption that the mind provides unmediated access to the external world, then we are led to conclude that since our observations are determinate, the stimuli we are observing must be determinate as well. By assuming that the mind offers unmediated access to the external world we are also assuming that there is no difference between our perceptions of the world and the world itself. Our dissatisfaction with quantum mechanics arises from the apparent disparity between the world of our perceptions and the world of quantum mechanics. However, this disparity is only problematic if we accept the naïve assumption.

In philosophical discussions of consciousness it is often taken for granted that one knows about one's own conscious states. I believe that not only is this assumption largely unfounded, but it has played a pernicious role in our formulation and assessment of the measurement problem. In order to better understand the nature of this assumption I want to briefly discuss a paper that has been decisive in shaping the way in which we think about conscious states.

In his famous paper "What is it like to be a Bat?" Thomas Nagel attempts to give a description of the subjective character of consciousness. Nagel argues that there is an element of conscious experience that is irreducible and not analyzable. He asserts that in order for any organism to possess conscious mental states there must be "something that it

is like to *be* that organism—something it is like ~~for~~ that organism.”<sup>32</sup> Nagel illustrates this point by using the example of a bat. Bats' sensory perception is well documented and understood. It is well known that a bat depends primarily on echo location to perceive the external world. The point is that although we know that bats use echo location, we will never be able to understand "what it is like" to use echo location and therefore "what it is like" to be a bat. The only way we could understand "what it is like" to be a bat would be to be a bat. Generally speaking, there is no way to understand the inner life of another creature from the perspective of our own experience since we are bound by the limitations of our own subjective experience.

In order to defend against the charge that there is not anything that it is like to be us, or that there is no subjective content to experience, Nagel argues that

*We know what it is like to be us* [my italics]. And we know that while it includes an enormous amount of variation and complexity, and while we do not possess the vocabulary to describe it adequately, its subjective character is highly specific, and in some respects describable in terms that can be understood only by creatures like us.<sup>33</sup>

Although it may not be accessible to a bat, my inner experience is in some way accessible to my awareness and can be, to a certain extent, verbally reported. I argue that Nagel's position on "what it is like" has been over generalized and applied to measurement problem.

One reason why quantum mechanics initially strikes us as so counterintuitive is that it is hard to imagine "what it is like" to observe a superposition. Not only are we unable to describe what would it would be like to observe a superposition, we could not even begin to try and *imagine* what it would be like. This is the assumption which leads

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<sup>32</sup> Thomas Nagel, "What is it like to be a Bat?" *The Philosophical Review* 83, no. 4(1974): 436.

<sup>33</sup> *Ibid.*, 440

us to suppose that there is a disparity between the world of quantum physics and the world of observation which needs to be reconciled.

The assumption that it is impossible to imagine "what it is like" to observe a superposition has played a role in our understanding of the measurement problem. The role of naïve assumptions in formulating the measurement problem is formalized by the "Wigner's friend" thought experiment. Essentially a more humane version of Schrodinger's Cat, the gun is replaced with a dial reading "spin-up" or "spin-down" and the infamous cat is replaced with a trustworthy friend we will call Evan.<sup>34</sup> An electron is sent through the Stern-Gerlach magnet. The point of this thought experiment is to try and imagine what happens next. If the box had been occupied by Schrodinger's cat we would only know about the outcome when opened the box. However, Evan can give a verbal report of what he observed while inside the box. Therefore, once Evan is added to the experiment we naturally assume that there was a definite outcome before we opened the box. This thought experiment is meant to emphasize the claim that we do not observe superpositions. From this experiment the measurement problem naturally arises: *when in the measurement process do superpositions become determinate?* However, this question is misleading due to its naïve assumptions. In asking this question we are apt to assume that by the time the perceptual information reach our brain there is a definite outcome.

The argument that there must be something wrong with quantum mechanics if it describes a superposition while the observer reports a single outcome might be unfounded. Instead, the problem may be our naïve assumption. To a certain extent, binocular rivalry and attentional blink confirm the plausibility of a determinate observation of a superposition. These experiments show us that there are ways in which

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<sup>34</sup> Alastair Rae, *Quantum Physics Illusion or Reality?* (Cambridge: Cambridge University Press, 2001), 64.

the mind mediates the information accessible to our awareness. If we reject our naive assumption, we can accept the possibility of determinate observation of indeterminate stimuli. Since observations of indeterminate stimuli can be unknowingly selective, we might reasonably conclude that our observations of superpositions are unknowingly selective as well. If this is the case, the problem of reconciling determinate observation with indeterminate superpositions disappears. It is possible that we are aware of observing only one state of a superposition due to a process of selection similar to binocular rivalry.

By claiming that it is plausible there is some process of selection which restricts us from having direct information about the states of a quantum particle prior to measurement, I am making an epistemological distinction. This can be seen as a partial validation of Copenhagen's claim that there is no problem to solve in quantum mechanics. This is because it appears as though the measurement problem is not really a problem at all. If we reject our naive assumption that our mind provides us with unmediated access to the external world there is no reason why we should be troubled with the distinction between the quantum world of superposition and the observational world of determinacy, the issue at the heart of the measurement problem.

However, this does not rule out Everett's ontological description which claims that there is a wavefunction which remains superposed after the measurement, while the mind's selectivity ensures that we can only be aware of one specific state in the superposition.

## *1.2 Implications for Quantum Mechanics: Bohm's Hidden Variable Theory*

The revision of our understanding of the observer and the measurement problem compels us to reconsider the merits of Bohm's interpretation. The desire to reconcile our subjective account of observation with physics' account of the quantum world is central to Bohm's formulation of the Hidden Variable Theory. In order to achieve this goal Bohm's theory gives a classical account of quantum phenomena. We can agree that the naïve assumption of unmediated perception is consistent with a classical picture of the world. Definite trajectories can be observed and predicted, and these trajectories exist before and after an observation. As observers, we report determinate outcomes to our measurements. If our mind does not mediate our perception of the physical world it follows that the physical world must also be determinate.

To a certain extent, Bohm's interpretation can be seen as an ad-hoc attempt to preserve a certain degree of determinacy in our account of the physical world. Unfortunately, preserving determinacy in the Bohm Theory comes at a high price. As I mentioned in the first chapter, Bohm's theory violates locality. This is central tradeoff in the Bohm Interpretation: determinacy for locality.

For the proponents of the Bohm Theory, a classical world is preferable to a world of superpositions. This is analogous to saying that the measurement problem is deeply unsettling. For proponents of the Bohm Theory, this is reason enough to justify the abandonment of locality. My point is that the world of superposition should not be so unsettling if we reject our naïve assumptions. The difference between determinate reports of observation and superpositions can be explained by the active role of the mind. If

binocular rivalry experiments show that we have determinate outcomes of indeterminate stimuli it is not unreasonable to suppose that we could have determinate observations of systems in superpositions.

The preference of a determinant physical world over an indeterminate one is understandable because of its congruence with our naive understanding of the way we see the world. But when we realize that observations of the world around us are complex and mediated, as exemplified in experiments studying attentional blink and binocular rivalry, it appears as though the Bohm interpretation is placing too much value on preserving a classical picture of the physical world. Therefore, to prefer the preservation of a classical world over the preservation of locality seems unreasonable.

### *1.3 Implications for Quantum Mechanics: The Many Minds Interpretation*

Insights from attentional blink experiments undermine the validity of Albert and Loewer's argument for the rejection of physicalism. We recall their third premise:

The state wherein A believes that  $|+\rangle_x$  and the state wherein A believes that  $|-\rangle_x$  are identical with certain physical states of A's brain. We will call those states  $B|+\rangle$  and  $B|-\rangle$ .<sup>35</sup>

Albert and Loewer argue that while the observer expresses a belief in a certain outcome, quantum mechanics dictates that the observer's physical brain states remain in a superposition, clearly violating premise (iii). Additionally, Albert and Loewer claim that a rejection of premise (iii) constitutes a rejection of physicalism. The problem with this

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<sup>35</sup> Albert and Loewer, 204

argument is the overly simplistic claim that expressed belief states are identical with certain physical states. Luck's experiment showed that there exist single brain states which sometimes correlate with belief states and sometimes do not. This suggests that there is a more complex relationship between belief states and brain states than a strict identity. Belief states are determinate; what they report is a brain state that is not determinate. Furthermore, acknowledging the complex relationship between brain states and belief states does not necessitate the adoption of a non-physicalism. Asserting that certain physical brain states are indeterminate when certain belief states are determinate still leaves open the possibility for a physical explanation of belief states.

#### *1.4 Implications for Quantum Mechanics: The Everett Interpretation*

The role of the observer is central to Everett's reformulation of quantum mechanics. For this reason alone, Everett's theory offers valuable insight. In fact, the observer is so important in this interpretation that Everett goes so far as to refer to conventional quantum mechanics as the "external observation" formulation.<sup>36</sup> Unlike other interpretations, the observer, according to Everett, is included within the wavefunction of the universe and Everett provides an explicit definition for the qualities of the observer:

As models for observers, we can, if we wish, consider automatically functioning machines, possessing sensory apparatus and coupled to recording devices capable of registering past sensory data and machine configurations. We can further suppose that the machine is so constructed that its present actions shall be determined not only by its present sensory data, but by the contents of its memory as well.<sup>37</sup>

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<sup>36</sup> Everett, 454

<sup>37</sup> Ibid., 457

Everett's description of the observer as a machine is clearly at odds with the picture of the observer which emerges from modern studies in cognitive science. It should be noted that Everett's thought experiment involving a machine instead of a human is merely a pedagogical device for elucidating his theory. I claim that by considering a more sophisticated observer we are able to look at the Everett Interpretation in a new light and the problem of determinate outcomes seems to disappear.

Through an examination of the distinction between the subjective and objective in the Everett Interpretation we are able to see that it is compatible with a sophisticated conception of the observer. In describing his interpretation, Everett is careful to differentiate between the subjective (reported experience of the observer) and objective (wavefunction). He makes it clear that the observer has a subjective experience that is different from the wavefunction. The most significant result of this subjective/objective distinction in the Everett Interpretation is that

It will thus **appear** to the observer, as described by a typical element of a superposition, that each initial observation on a system caused the system to “jump” into an eigenstate [determinate outcome] in a random fashion and thereafter remain there for subsequent measurements on the same system. Therefore...the probabilistic assertions of Process 1 **appear** to be valid to the observer described by a typical element of the final superposition.”<sup>38</sup>

At first glance the claim that Process 1 dynamics are an illusion of subjective experience seems doubtful. However, when we see that this is analogous in some ways to the single clear picture seen by the observer in binocular rivalry experiments Everett's claim seems more reasonable. If we understand "subjective experience" to roughly correspond to the verbal reports of observations, Everett's subjective/objective distinction makes sense. In

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<sup>38</sup> Ibid., 459

addition, the Copenhagen Interpretation can be seen as the subjective limit of the Everett Interpretation. The Copenhagen Interpretation gives an epistemological view that is completely consistent with Everett. However, by postulating the universal wavefunction Everett adds an ontological element to the Copenhagen Interpretation. This means that Everett's universal wavefunction is the ontological description that Copenhagen refuses to provide.

The Everett Interpretation can now be seen as a somewhat Kantian theory. There is the world of the wavefunction, the world of "things in themselves," to which we have no direct perceptual access. This limitation is due to the fact that our observation of the wavefunction is mediated by our minds. However, our verbal reports of observation constitute a subjective account of the wavefunction if we incorporate collapse dynamics. Experiments such as binocular rivalry and attentional blink should convince us that the mind of the observer might reasonably account for the transition from superposition in the external world to determinate outcome in the subjective verbal account. Therefore, the nagging problem of reconciling the branching wavefunction with our subjective account of observation disappears.

The question now arises: why not just stick with Copenhagen instead of going to all the trouble of postulating a universal wavefunction? The answer is that postulating a universal wavefunction allows us to solve some of the problems facing the Copenhagen Interpretation as well as expand the empirical content of quantum mechanics. In the first chapter I mentioned the possibility of an ontological interpretation providing a solution to the seeming incompatibility of quantum mechanics with relativity. Indeed, Everett believed that his interpretation "may prove a fruitful framework for the quantization of

general relativity.”<sup>39</sup> Successfully unifying quantum mechanics and general relativity would be a tremendous benefit of this theory. In addition, containing the entire universe in the wavefunction increases the number of phenomena quantum mechanics can describe. For instance, a quantum mechanical account of the big bang is now possible with a universal wavefunction. Under the "external observer" formulation of quantum mechanics this would have been difficult given the lack of observers present for the big bang.<sup>40</sup> These considerations show that the postulation of an objective wavefunction unequivocally offers significant interpretational benefits.

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<sup>39</sup> Ibid., 462

<sup>40</sup> William Wothers, discussion with author, Williamstown, MA May 10 2005.

## Conclusions

I have tried to show that the role of the observer is exceedingly relevant to evaluating interpretations of quantum mechanics. Whether we are aware of it or not, our understanding of the human mind is influential in our formulation of scientific theories. A naive conception of the mind has given rise to unnecessary confusion and speculation in quantum mechanics. The measurement problem, our original criticisms of Everett, the impetus for creating Hidden Variable Interpretations, as well as the question "what is it like" to observe a superposition, are all based on naïve assumptions about the mind. After a careful consideration of a number of interpretations in light of a more sophisticated conception of the observer, I am inclined to accept the basic structure of the Everett Interpretation as the most reasonable explanation of quantum phenomenon.<sup>41</sup>

Some physicists might be disinclined to take these arguments seriously; Everett himself resisted relinquishing control over the investigation to psychology. A positivistic view of science rejects the possibility of philosophical ideas having a meaningful influence on scientific theory. If science is to achieve objective knowledge it must be self-sufficient. However, incorporating philosophical analysis into the evaluation of scientific theories is by no means a novel methodology. By taking this approach, I am working in the tradition of scientists such as Einstein and Bohr who felt that a broad picture of the universe must be taken into account while making scientific deliberations.

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<sup>41</sup> There are a number of other difficulties with the Everett Interpretation, such as the problem of preferred basis, but I nevertheless believe that the basic conception of the Everett Interpretation is the most sensible of all the interpretations I have discussed. For a discussion of these problems in Everett see Albert and Loewer, 200-202.

This leads me to one of the more broad conclusions of this essay: in the case of quantum mechanics, philosophy is a part of science. By demonstrating how our views of the mind can influence our formulation of scientific theories as well as assist us in analyzing and rejecting them, I want to make the point there is a complex process whereby science (e.g. studies of attentional blink) influences our folk concepts of the mind and these concepts in turn influence science by aiding in our interpretations of quantum mechanics. This dynamic process, mediated by philosophy, is very much a part of science.

The role of thought experiments in our analysis is also instructive. In this essay I have employed a number of thought experiments including Schrodinger's Cat, Wigner's Friend, and Heisenberg's Microscope. These thought experiments are a central part of our scientific enterprise, yet they are not empirical experiments, they "instantiate phenomena they concern not literally but metaphorically."<sup>42</sup> These thought experiments are integral in helping us to understand the issues at hand (or further confuse them). This is because "the success of a thought experiment turns on the accuracy and adequacy of its background assumptions."<sup>43</sup> And as we have seen, some of these thought experiments employed faulty background assumptions. The function of thought experiments in devising testable theories further emphasizes the way science develops through a complex process which is not limited to empirical observation of objective facts. Furthermore, it is through philosophy that we can expose and discard these faulty background assumptions. Methodologically, I suggest that it is beneficial to try and

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<sup>42</sup> Catherine Z. Elgin, *Considered Judgment* (Princeton: Princeton University Press, 1996), 180.

<sup>43</sup> *Ibid.*, 180

incorporate a wide variety of considerations (such as the role of the observer) into our analyses of scientific theories in order to help resolve seemingly intractable problems.

## Works Cited

- Albert, David and Barry Loewer. "Interpreting the Many Worlds Interpretation." *Synthese* 77, (1988): 195-213
- Barrett, Jeffrey. "Everett's Relative-State Formulation of Quantum Mechanics." *Stanford Encyclopedia of Philosophy*. <http://plato.stanford.edu/entries/yn-everett>.
- Bell, J.S. *Speakable and Unspeakable in Quantum Mechanics*. Cambridge: Cambridge University Press, 2004.
- Butterfield, Jeremy. "Quantum Curiosities of Psychophysics." *PhilSci Archive*, March 9, 2001, <http://philsci-archive.pitt.edu/archive/00000193>.
- Einstein, Albert, Boris Podolsky and Nathan Rosen. "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 47, (1935): 777-780.
- Elgin, Catherine Z. *Considered Judgment*. Princeton: Princeton University Press, 1996
- Everett, Hugh, III. "'Relative State' Formulation of Quantum Mechanics." *Reviews of Modern Physics* 29, no. 3 (1957): 454-462.
- Faye, Jan. "Copenhagen Interpretation of Quantum Mechanics." *Stanford Encyclopedia of Philosophy*. <http://plato.stanford.edu/entries/qm-copenhagen>.
- Feinstein, Justin, et al. "From Sensory Processes to Conscious Perception." *Consciousness and Cognition* 13 (2004): 323-335, <http://www.elsevier.com/locate/concog>.
- Kanwisher, Nancy. "Neural Events and Perceptual Awareness" *Cognition* 79, (2001): 89-113, <http://www.elsevier.com/locate/cognit>.
- Luck, Steven J. et al. "Word Meanings Can be Accessed but not Reported During the Attentional Blink." *Nature* 383, (1996): 616-617.
- Nagel, Thomas. "What is it like to be a Bat?" *The Philosophical Review* 83, no. 4(1974): 435-450. <http://www.jstor.org>.
- Rae, Alastair. *Quantum Physics. Illusion or Reality?* Cambridge: Cambridge University Press, 2001.
- Redhead, Michael. *Incompleteness, Non-Locality and Realism*. Oxford: Clarendon Press, 1987.
- Stone, Abraham. "Does the Bohm Theory Solve the Measurement Problem?" *Philosophy of Science* 61, no. 2 (1994): 250-266. <http://www.jstor.org>.
- Wittgenstein, Ludwig. *Philosophical Investigations*. Oxford: Blackwell, 2001, 41<sup>e</sup> .