Spring 2018

Untangling Entanglement and the Reality of Science

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UNTANGLING ENTANGLEMENT AND THE REALITY OF SCIENCE

A thesis submitted to
Regis College
The Honors Program
In partial fulfillment of the requirements
For Graduation with Honors

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Preface and Acknowledgements

I will always have a fascination with the unknown universe and I hope that this curiosity will continue to grow and guide my own journey as a scientist. I would like to accredit Regis University for allowing me to learn and explore. The time I have spent here has provided me with the tools and insight to pursue new ideas and discoveries as well as cement my own passion and interest in chemical research.

I want to first thank my advisor, Dr. Jean, and reader, Dr. Gray, for all their time, mentorship, and assistance throughout the entirety of the process. They have introduced me to the realms of physics and quantum mechanics through their classes. They have also pushed me to think further about concepts within these topics and improve as a writer.

I would also like to thank Dr. Kallan, who has been a great mentor to me through the past years and opened many opportunities for me. Furthermore, I would like to thank the entire Chemistry Department at Regis University for their time and help throughout these years as each professor has made my experience unique and memorable. I would also like to thank Dr. Howe, Dr. Kleier, and Dr. Narcisi in the Honors Program for creating this opportunity. I am grateful for the opportunity to meet so many wonderful people and the chance to deepen my own knowledge and understanding of reality.

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Chapter 1: “Virtue” of Scientific Theories

In our advancing scientific society and technological evolving world, the existence and usage of scientific theories cannot be undervalued due to their incredibly predictive powers. Commonly, these scientific theories are seen to govern science as they establish observational parameters for natural phenomena, usually funneling into technological applications and advancements. Specifically, a scientific theory is established to provide an explanation and future predictions about natural phenomena based on pragmatic evidence from our assumed deterministic nature of the world. Theories have upheld themselves to be more than a mere guess but rather supported by the results of controlled and well-thought-out experiments. This implies that given an observation in the universe, scientific theories will reliably allow a person to draw valid conclusions about it. The problematic consideration is the thought process between initial and final observables. Reality should only have one explanation, so with many theories, the difficulty is accepting the appropriate all-encompassing one.

To provide a general example of the above thesis, say that given scientific theory A, it states that if X and Y are present, then Z occurs. The purpose of A is to explain Z from initial X and Y, involving some thought process and ideology behind. The complication is when there exists scientific theory B that also predicts Z from X and Y. The difference then between A and B is their ideology. Experiments will demonstrate that Z can be shown from X and Y but offer no explicit explanation. The goal of the scientist is to maneuver this implicit information into an explicit explanation and thus is open to deviations. The theory is guided by the ideology held by scientists.

We have the assumption that there should be at most one explanation for a phenomenon in which is reflective of reality. With any more, there is certainly to be a debate. Throughout history, theories for the same phenomena have been formulated and repudiated when countering evidence is given (Kuhn, 2015). Notable examples are Spontaneous Generation, the seemingly random creation of life from inanimate matter (countered with finding microorganisms transferred in the air), or a flat Earth, the idea that the Earth is flat in shape (countered by measurements indicating a sphere-shaped planet). However, when there does exist two or more theories for a phenomenon and none has yet to be rejected, we should accept one. It is always this *or* that, never this *and* that. Again, this is problematic because experiments produce the same empirical evidence from the same initial conditions. The key interest is how the theory bridges those two together. There may not be any other supporting evidence that indicates which theory to claim. Thus, it may turn to which is more ideologically aligned with one's concept of reality. The option to choose how we want to "connect the dots" is present, along with a choice of writing utensil to form a line in the end.

This is difficult as there is no check that confirms our assumptions about reality. The theory may not be reflective of reality at all, yet it still is predictive. If theory A is not necessarily representative of objective reality, yet it still explains why X and Y produce Z in an acceptable manner, it can be argued that it still serves its purpose as a scientific theory. Logically, different steps in differing sequences can be taken from the same axioms to arrive at the same answer. Theories are similar in nature as they require humans' inference and intricacy to form a process in which we show how X and Y go to Z.

Models aim to simplify explanations and integral components while still mimicking the purpose and functions of a system. Theories arguably behave as models – their aim is to provide us with a better understanding of phenomena. However, this comes with a price as models leave out all the details through simplification and reduce what the model is trying to exemplify. It explains the natural world but does not strictly acknowledge reality (Kuhn, 2015). The debate then is whether a scientific theory is a true view of reality or simply a model of reality. This idea of scientific theories is prominent in the field of quantum mechanics, a subfield of physics in looking at fundamental subatomic particles of nature. Here, the scientific theories that are presented have much debate and controversy surrounding them in their decided mapping of reality.

On one side, a theory pertains to real physical entities and attempts to describe how they interact with each other in the universe. Theories are grounded in the reality they actively describe (Einstein et al, 1935). On the other side, theories are only present to provide us with a way to think about reality, which may not be the "right" way. We think science is factual and that the ideas of science directly inform us of phenomena in the real world. However, reality may be complex for us, so theories only help us understand the conclusions that we draw from it. It may not be necessary that there is an exact physical correlate for what the theory states. This concept may be philosophically disturbing to some since science is seen to reveal absolute reality.

Another approach to thinking about this is to consider our complete reality as a system with complex interactions between objects. If a theory were to describe the complete reality of this system, it would list every moving part and their interactions with everything in that system. If a theory were just a model, we could reduce the system into an apparatus that has an overall function. This works as the apparatus considers the purpose of the system but does not recognize the intricacies of its components (Jean, 2016). We can explain the system then in terms of this simplified apparatus. It just lacks a referral to the actual reality of the system's part.

The "virtue" of a theory is the one we more readily accept those two ideas for a scientific theory. The "virtue" of it comes from our philosophical self in defining it. This is most highlighted in the field of quantum mechanics with its particles interactions.

A quantum theory that exhibits this behavior is quantum entanglement. It is a theory that finds itself in the debate of objective and presents philosophical notions for its acceptance. Quantum entanglement is the phenomenon in which particles that are generated will proceed in a manner where their definitive existence cannot be stated without a direct reference to the other. Measurements taken on entangled particles will have correlating properties, even if they are separated at great distances. The problem that arises in understanding how these related states exist between the particles at great distances is how they "know" of each other's state when an observer measures the state of one. This causes a "collapse" of the other state as if the information has traveled between the two. Yet experiments have shown that this information transferred would have to be quicker than the speed of light (d'Espagnat, 1979). Proposed theories involve a significant number of philosophical implications because of that.

An example we see in quantum mechanics for examining the reality of a scientific claim is the proposed particle and wave duality of light. It is a wave because it demonstrates an interference pattern that resembles a wave in the double-slit experiment but resembles properties of a particle as part of the photoelectric effect which photons eject electrons off metals and semiconductors. It has properties of both a wave and a particle, yet in an orthodox view, it is a wave or a particle when completely observed. This duality presents an explanation that let us think about light as both a particle and wave. This enters the realm of realism in which the theory looks at it if the light was in two simultaneous states, while it should be thought of as one. The extent we hold realism dictates the extent we can accept that the particle is both a wave and a particle, rather than just one or the other.

Along with realism, there are other philosophical issues that can be found in these theories. They are determinism, localism, and realism. These ideas will be explored alongside the history of quantum mechanics, focusing on the developments leading up to quantum entanglement and the phenomenon itself. Philosophy and its role in the field at that time may have affected the conclusions of quantum entanglement now made. Quantum entanglement addresses all three of these philosophical concepts in working towards explaining it as reality or just a way to explain occurrences.

The nature of quantum mechanics poses theories that exemplify ideas of probabilistic nature. The historical context in which these theories are brought up in must be considered. Quantum theory arose in the 1920s during a time of positivism, a philosophical belief in which much of the physics at the time was found in by (Bacciagaluppi & Valentini, 2013). The idea that the theory follows is that it does not need to have a direct mapping onto reality but rather leans towards a model backed up with logical proof. A logical process is necessary for us to make scientific theories and this field should not differ. Our human comprehension of the world should again appear accurate enough and what we observe is close to the truth as possible. Whether the theory truly reveals the truths of reality or merely provides us with a way to think about it, our logical reasoning is present in either of those two methods. If the logic is sound, then the explanation is a viable one.

Preceding quantum mechanics is classical mechanics, which has a directly opposite nature in relation to determinism, that all future outcomes are determined by pre-existing values. Given all the needed variables, the trajectory or the behavior of any object can be calculated and extrapolated. This contains that very deterministic viewpoint as everything can be determined down to a point given all the necessary information. Einstein was in support of this view in his thinking and his theories, even in his idea of relativity. Opposing this was de Broglie and Bohm who have submitted theories and ideas that counteract both the realist and deterministic nature of theories starting early in the 20th century, which does much more support to theories that only act to model reality rather than replicate it (Bacciagaluppi & Valentini, 2013). However as later seen, both their works and theories arrive at the same conclusion which puts into question only the way to think about reality and how it functions, and even the significance if the practical conclusions are arrived at in either manner. I believe that the process is important to understanding how we view reality and does affect the significance when we are to look to applications pertaining the theories. Applications may demand a theory to adhere directly to reality, however with given experiments, this may not always be necessary (Kuhn, 2015). Again, if we understand the purpose of the system and how the important parts of it work, we can manipulate in ways using just that information. This leads to the enigma of what is there and what do we know about it.

Localism is another distinct idea if we are to look at the differences between classical physics and quantum theory. Interactions that we may be familiar with works on the assumption that for one entity to move from A to B, it must pass through space in-between A and B. Quantum entanglement as briefly explained above, violates this idea and these theories must be formulated to conceptualize where the thought needs to move from there. A deterministic approach would have suggested the idea there is still a space between A and B that the particle moves upon, however unknown to us humans (Wiseman, 2014). This is known under hidden variables theory, which is a theory formulated that demonstrates an attempt at an explanation of a phenomenon revolving around the idea of determinism. We see that it is just as viable as another proposed theory for there is much unknown. It follows a deterministic view, everything can be explained once we know all the variables reflected. We are just missing some now and cannot fully look at quantum entanglement, but it does occur in actual reality and maintains a deterministic nature. The scale of quantum entanglement is important to note as direct observation is important in the concept determinism.

Another point to consider is that quantum theory is one of measurement as the significance of measurement is very important to its theories and conclusions. This also returns to the dichotomy between an actual reality versus one that we attempt to model. Measurement perhaps has a significant role in quantum entanglement and mechanics as it implies a collapse of states, returning the idea of non-realism and statistical existence. This means that a particle can be in one of two opposite yet equal states, yet we do not know which one until we measure it. To express its states when measured, it is half one state and half the other state, paralleling light duality. Intuitively, we abide by the logical assumption that one thing can only be that one thing; however, quantum entanglement provides evidence that it does/best way to describe its implications and conclusions. We could see that as a theory that gives us a way to think about reality but not actually a definition of reality as it helps us best to understand that it is in both states until we put a definitive measurement on it; we can understand this as a probability. However, if we decide we are content with giving up realism, then while we do not observe the particle, it does not exist in either state.

If we do not observe something, it should still exist and is bothersome to think otherwise. It is perhaps selfish to think that our human presence provides some sort of influence to the other existing entities of the universe. However, this is also dependent on philosophical viewpoints. The role of measurement is complicated. We return to the notion that theories completely represent the universe and such a measurement can be implanted at any time and give us a definitive state. That definitive state exists independent from measurement. On the other hand, perhaps that statement is not definite and only exists when we measure it. This appears to be more indicative of the idea that theories only model the universe, or rather this is the best way to think about this as we do not truly know how such behaves and through this model, it is best represented to portray the resulting conclusions. Since they both provide the same results, this leaves us to decide which one we agree with philosophically or perhaps we rather be. The reality is that we must choose whether reality is objective or subjective in that sense.

Nature is simple and perhaps the simple ways of thinking are the best in proceeding to figure more about nature and understand it (Kuhn, 2015). This would play into the part where realism and determinism hold true. We cannot dismiss the more complicated and nuanced entities we have observed in our universe. Simple thinking can only take us so far, but we do have our logical minds to rely on still.

Thus, we also rely on our philosophical self to adopt which we more agree with. This differs between notable scientists as well. One scientist, John Bell, derived an inequality disproven by experimental evidence to look at which philosophical ideals one can consider in examining quantum entanglement halfway through the 20th century (Harrison, 1999). We should have to consider if we choose fully an ideal, the losses that are created from the overall theory to have it consistent with all our views. Something that has a definitive state can have a duality between states in which some evidence suggests.

The scope of this work is to examine the meaning and significance of a scientific theory in the context of whether the theory has been formed to explain an objective reality versus a theory used to give meaning to a reality that is subjective or formed in a way we can understand it. This distinction ultimately rests upon our personal choice. With each, there lie separate consequences in the following philosophical guidelines around that personal idea of science. This is most prominent in quantum mechanics and quantum entanglement is a phenomenon that forces us to make philosophical choices. This debate is not new as historic events leading up to the theory exhibit the initial framework for this problem along with the philosophical nature of the debate. Science should work towards accurately reflecting reality, and this causes complications with phenomena, such as quantum entanglement, where we must then choose between the now seemingly opposing philosophical tenets to reflect that initial acceptance for the reality of science.

Chapter 2: Historical Context
(Classical Physics to Beginning of Quantum Theory)

To begin our inquiry on quantum mechanics, we must first derive the philosophical nuances from its roots – classical physics. The ideas surrounding classical physics can provide insight into how we perceive the ideas and claims arising from the theories in this field. They can offer comparisons in which can serve as a basis for determining what these ideas truly offer about reality.

From our undergraduate classes, we may already be familiar with classical physics as it is the focus of the first year for physics coursework, which is usually a requirement for science/engineering-based majors or future graduate studies in healthcare. Separated into Newton's and Maxwell's equations, each a semester is divided into mechanics and electromagnetism, respectively. We can examine the significance that both Newton and Maxwell provided when regarded to classical physics. The experimentation they underwent leads us to the general philosophical items that surround classical physics. While each contributed equations and theories that may appear incomparable (comparison of motion/gravity to electric/magnetic dynamics), their deviations and conclusions share a similar scientific background.

Newton is distinguished as the first person to offer the best explanation of "how the universe worked from the smallest to the stars and galaxies" (Caleon, 2015). He offered his law of motions and, from our perspective now, a "basic" understanding of gravity. Importantly, it has been expressed that Newton did have a theological side that was asserted in his writings. Newton claimed that the motions of bodies in space “did not have their origins in mechanical causes” and that “most elegant system of the sun, planets, and comets could not have arisen without the design and dominion of an intelligent and powerful being” (Caleon, 2015). We can see that he attributes the findings of his scientific inquiries to have been constructed by a divine being, given its complexities and intricacies. He also advocated that God was present and engaged in the form of equations. This also shows that Newton believes that there was a reality present, in the form of a God’s creation. In that these intricate systems truly existed because they were forms of creation and we had the ability to go forth and understand their elegance. This alludes to realism, the philosophical concept that entities exist outside our conceptual understanding of reality and the universe. It was also recorded that he was pragmatic in the sense of his high value of experiments. As seen from the famous parable of the apple falling on his head to allow him to conclude the existence of gravity, there is an emphasis on how observations and manipulations of matter lead Newton to his theories and claims. His explanation for natural phenomena arose from deduction (Caleon, 2015). While there is a relation between his religious beliefs and the work he accomplished, there is an objective approach to reality in that he was trying to understand the reality through intelligent design.

Maxwell derived the electromagnetic theory, which paved the way for many unifying physics concepts. Like Newton, Maxwell also expressed a belief that a God was present in nature which would allow for him to understand the underlying guiding fundamental principles buried under the observable phenomena in the world (Caleon, 2015). His remembrance mostly came from his equations, ones that linked electricity, magnetism, and light. Other known scientists at the time, including Faraday, Ampere, and Gauss, had their work examined by Maxwell. Each individually contributed a certain aspect of the entirety of Maxwell's equations; they each theorized distinct features about one of the components that Maxwell eventually compiled together. This development demonstrates that these key scientists shared a similar approach towards their work and the philosophical ideas they maintain. Given Maxwell's own nature, like Newton, he operated with realism. The discoveries found must resemble objective reality for the separate theories are shown to meet on a real plane. Maxwell found relations from his observables in searching for those fundamental principles that should guide a reality. Our scientific advancements can give us a conceptualization of the universe that has real correlates. Maxwell was driven by his belief that the workings of the universe designed by a creator were intended to be discovered by humans (Caleon, 2015). It can be argued that given the time of Maxwell and the "unseen" electromagnetism he worked with, it may not appear that his conclusions stay fully within realism. However, his deductions can be derived from purely pragmatic means using Newton's mechanics and relations found between forces and energies (Greenham, 2017).

Much of our world is perceived on the guidelines that encapsulate classical physics. To return to that first-year physics classroom, classical physics is inherently deterministic. In a simple classical physics problem, we are given pre-determined values for the properties of a system; we can then use those values to predict and calculate certain states that the system will be in over a range of time. Take a projectile motion problem for example. We can look at projectile's trajectory in looking at its velocity and position from an initial launch. Given such known variables, we can find the missing ones in a system. This resembles a deterministic mindset that governs the principles of classical physics, as seen in the theories that have arisen from it. Newton's laws of motion predict this behavior and give the ability to do so. More specifically, they state if the mass of the projectile, the initial speed and angle of its launch is known, the states of the projectile at any time can be known. This presents a realist view and that the relationships between the variables and the projectile's state is causal. Another significant component of this representation in respect to realism is that the human act of taking a measurement at any point in time for the system has no effect on the system or any of its resulting behavior.

Another consequence of Maxwell and Newton under classical physics is the representation of matter. In accordance to Newton, matter is localized in particles to obey his theories and equations of motion. On the other hand, with Maxwell, his equations dictate that entities exist in waves in following the parameters set up by his theories. While this may appear conflicting for classical physics, both sides were able to exist concurrently as certain elements with portioned into one state or the other, decided through observation and deduction. Both particles and waves were the existence of matter in true reality and were not just conceptualize ideas to process entities. For most of the 17^{th} - 19^{th} century, this view of physics existed, grounded within realism and determinism after their initial inception (Jean, 2016). This provides that scientific theories express "laws" about the universe that we have discovered.

Overall, looking at the philosophical implications of classical physics, we can assume that there are ideals that guide it, some seen previously. The first being realism, meaning that all entities objectively contain pre-existing properties before they are measured (d'Espagnat, 1979). This also highlights the significance of measurement/observation. Measurement is through our human senses and empirical ability in conceiving the world. Thus, measurement is very biased in terms of humans and central to our observations as we must remember that these fundamental principles of the universe are through our human scope. This is under the assumption that there are fundamental principles of the universe, which are not placed or conceptualized by our own human nature; that our distinguishing of common universal laws is not human-centric. Realism claims that they exist with or without human existence. Thus, our measurement of any universal phenomena would not be affected by our physical observation and quantized of it. We should not think that we have any persuasion of universal phenomena that would occur differently selectively towards us.

Stemming from determinism, classical physics also addresses causality which is the perception that an occurrence must have been caused by another occurrence. This gives the notion that our universe proceeds forward by the actions and interactions in its previous states. On a simpler scale, a phenomenon that occurs usually contains a reason could be another phenomenon. We see causal relations and often define relations in nature through causal ones - for if A happens, then B is sure to follow. In terms of classical physics example, if we were to throw the ball, the ball would fly through space we threw it in on a trajectory determined by the parameters of that toss. To many, these ideas may seem philosophical because they follow the reasoning that we have encountered within our academic growth. To be fair, science does proceed in this deductive manner.

Localism is also a significant aspect of classical physics. From Einstein, there is nothing can exceed the speed of light and interactions occur at a point in space and time (Wheeler, 1975). Cause and effect relationships must be local in time and space between objects that exist, regardless of our existence (Wiseman, 2014). These relationships also take no influence from our observations, during the time of observation or moments afterward. Definitions within classical physics show to follow locality (Jean, 2016).

The other largest aspect of classical physics is called separability. This is the notion that particles exist in time and space in a manner that they are localizable and countable (d'Espagnat, 1979). This follows the guidelines for realism as matter can have definitive properties at a definitive time. If we were to examine particle A, we would know that it would have definitive properties. There could be a spectrum of the properties it may hold, but it would only contain one ensemble for those properties. It cannot be two separate, opposing properties at once and even without measurement, it can be deduced it is in one of its possible states. The essential part is that conclusions and general claims can be made about a particle of interest with a certain confidence.

These philosophical ideas occur in classical physical and perhaps, a general understanding of our scientific realm. Even outside of physics, these ideas are commonplace in understanding our surrounding interactions. Our reality is real and there is objectivity to the world that surrounds us. We would like to believe that we exist and not in some sort of simulation. The action I do takes time to interact with sometime else in space, given the distance, and that I must interact within the space and time we exist in. I can be expressed in values along with anything else given the effort, which does not change regardless of another's observation. Interactions still occur outside the human realm. These conceptions are challenged as quantum mechanics are introduced entering the 20th century.

While it can be argued that multiple discoveries lead to the birth of quantum mechanics; it came from a culmination of discoveries. The first notable case would be the discovery and assessment of blackbody radiation. This refers to an object that emits thermal radiation due to oscillators in its composition, or energy, that is exchanged with oscillators of the electromagnetic field. This is important to quantum mechanics because this exchange consists of a change in discrete amounts, noted by its Latin root *quanta*. We see that this development resolved the UV catastrophe in which the radiation from blackbodies was not accurately determined at high outputs with classical physics but resolved with a quantum methodology showing importantly, energy is quantized.

Here we return to the phenomenon of the photoelectric effect. This suggests that light behaves like a particle rather than a wave. The experiment that leads to this new found claim exhibited data that showed light contains all the properties that a particle would. This demonstrated a new-found perspective on light and perhaps give ways to rethink other forms of electromagnetic radiation. However, this was troubling to some extent. It was understood that light behaved like a wave, yet in this case, it was able to be portrayed as a particle. From this, a couple of conclusions can be made from a philosophical standpoint. It causes us to rethink our conceptualization of light. It challenges our notion that we can conceive and understand the reality that we refer to as light, particularly in the framework of the scientific community's perception. Here, we see a distinction between a theory that directly explains reality because there is the assumption that there is a realistic entity we refer to which has properties in realistic ways.

However, presented in this case, light is now shown to have different properties that change our conceptualization of it. This supports the idea that our notion of light is a theory rested with the belief that theories are just models for us to use in understanding reality and thus, that is the "virtue" of the theory.

Following, Bohr designed a planetary model for the hydrogen atom. Bohr assumed that the electron has a stationary orbit allowing for its angular momentum to be quantized in meaningful quantities, values that have other physical significance. This was derived from the emissions lines of atomic hydrogen; he was able to observe that there were distinct allowed energy levels that could be mathematically expressed. Here we come up with expressions that present this model to replicate the dynamics between an electron orbit around its hydrogen nucleus. As we see more refined models of the hydrogen atom, we see that Bohr's theory did its best in trying to replicate reality and did come to the overwhelming conclusion that there are definite orbital states that the electron could be located at in. These still reflect the ideals of classical physics. The idea that we can determine the state of the electron location based on possible energy levels shows determinism and the theory that definitive separate states exist shows separability.

In terms of quantum mechanics, this takes away from our idea that objects move continuously through space and time and in discrete and distinct methods, at least on a subatomic level. This became a major highlight of the now increasing field as that idea counteracts the philosophical implications for science we gained from classical physics.

The theories of quantum mechanics and quantum entanglement excelled following those discoveries in the 19^{th} century as the first Solvay Conference was held. The conference aimed to gather experts to work on outstanding problems in the field of physics and chemistry. The first one presented the new-found dichotomy between classical physics and quantum theory, as radiation and a new idea of "quanta" was introduced. The fifth Solvay conference was a landmark conference as a more definitive idea of quantum theory was presented by Bohr and Einstein (Bacciagaluppi & Valentini, 2013). However, the presentation of these new ideas caused a debate - not in the science, but on their interpretation and cohesion into the scientific framework. The conference could be divided into two parties. One would be considered the realists; science addresses the collective reality we share to the extent that our scientific theories are true representations of what surrounds us. Shared among most scientists in that era was a philosophical idealism of positivism. Positivism is the strong belief that our conclusions should arise from empirical evidence and that our knowledge of natural phenomena is certain in accordance to reality (Kuhn, 2015). A strong contemporary of these beliefs was Einstein. This community rejected the concepts of metaphysics, the abstract portrayal of theories to allude to reality. Metaphysics aligned with the other side in its view on reality. On the other side Bohr and his peers, known as instrumentalists, maintained that theories were just instruments or models that serve as an end to a mean for human understanding. They did not represent the true reality that we face before us. Reality must come from a deduction of experience rather than levels of induction then become one of the contending points in this debate (Bacciagaluppi & Valentini, 2013).

It can be argued that we can never reach reality through our inductions, but perhaps that is the best way to reach an understanding of it. If we assume that we can never fully understand the reality that surrounds us, due to our human capabilities, we must settle that the theories we suggest are just models of the objectivity. However, if we assume that we have the capacity to reach true reality, then we can keep working towards finding a representative theory of reality through experimentation. Both approaches rely on the underlying basis that there is a large portion of that scientific approach based on one's internal philosophy and their perception of reality.

Despite the conception, that science is objective, at its core, science is the name we give to ourselves in trying to understand the universe, through our own lens. The personal merits that we hold are a factor.

A theory introduced by de Broglie presented an opposing view to the wave and particle dichotomy of light at this conference. It suggests that particles had an associated wave underlying it and would produce the same evidence as seen in the previous cases. This proposition was not taken seriously at the time (Bacciagaluppi & Valentini, 2013). In terms of just the theory, it showed how theories can be formulated to produce the same results or conclusions as other ones. This means given the same evidence, theories and their deviations vary from scientist to scientist because they align with their own beliefs.

From the conference, the Copenhagen interpretation of quantum mechanics arose and with them, a set of their own philosophical implications guided strongly by Bohr. Since classical physics is more closely related to the ideas behind realists, we see an uneasiness these interpretations of quantum mechanics (Bacciagaluppi & Valentini, 2013).

A quantum mechanical system can be represented through a wavefunction which is a mathematical function that evolves in time. The average values for observable properties of the system can be calculated from such. Finding the average gives a sense away from separability and deterministic. Here, an introduction to indeterminism and a probabilistic nature is given. Average implies that a true value cannot be known, and the average must be taken from values that fluctuate between a limit. The belief is that the property should be distinct and hold a value regardless of other factors. This is difficult to think of realistically because the average does a better job in modeling that the value is between many different values. Averages also incorporate all those values into a single mathematical description. It is best to represent it as an average, modeling the reality in an expressible manner.

The second implication is that the classical properties to describe particles in classical physics are not objectively real in the quantum world. Quantum particles are expressed in a probability of states, diverging to that indeterminism and probabilistic nature. This view is based strongly on philosophy. We must understand that those theories imply that particles do not have states until we physically observe and measure them. Moreover, that these states are not "real" until we determine to examine what state they are in. This makes sense from a probabilistic approach. In cases where we do find a particle in a certain property half of the time, and in the opposite property the other half, the best descriptor would be assigning a probability mathematically in which the particle exists in two states. Until we see the results of a coin flip, we cannot know anything but the probability. This demonstrates a thought process in which if we were to think about the particle in respects to that property during a moment of observation. We assume that it exists outside of human existence and must contain those properties outside our measurement. The challenge we face is the perception of that property in those times. The difficulty is finding the appropriate definition of that property when we do not know which state it is in, but it does still exist. This expression demands us to claim that it is half in one state and a half in the other, almost represented as a duality. Yet, we know it must be in one state or the other and does not truly exist as that probabilistic dual state. The proceeding is then to realize which side one is more comfortable in believing.

The probabilistic identity does appear more to be a model for which to best represent the system, in the cases we believe that it is better to have a better conceptual understanding of this dynamic and give up understanding the absolute reality. This is the case because it is hard to interpret a realist view of how the particle can seemingly compass both states. The act of measurement can resemble a human-centric in which we somehow bring it into existence carrying its properties along with it. Measurement is also then the only “certain” way we know that property if we were to exist in a place that is probabilistic. We cannot know for certain until measured.

Going along, paired properties cannot be both known with precision simultaneously, shown in the famous Heisenberg's Uncertainty Principle. By knowing either position or velocity, we lose grasp of the other as we cannot measure both at once, given their nature. This sort of complementary duality presents itself in other aspects of quantum mechanics, also famously in wave-particle duality. It faces the same consequences however in that both particle and wave component cannot be expressed or shown at the same time.

These philosophical outcomes lead us to a fork in the road where quantum mechanics show present theories that are more representative of a model in the concepts they attempt to define. This is because they seem to be opposing against the notion of realism, especially our understanding of definitive existence without measurement or observation. Thus, it is conceptually better to accept it as a model. In the model, we can forgo realism because there are no real philosophical consequences. We will see that some would argue our best interpretation of reality rest within the statistical and probabilistic realm alongside quantum mechanics in which its theories are just models for the inexplicable objective phenomena. As we continue forward in this historic development, entanglement will be proposed, define, and studied by scientists. Most importantly, their philosophy shaped the theories moving forward in their intention of model versus reality.

Chapter 3: Historical Context (EPR Paradox to Entanglement)

Despite a uniform perspective of classical physics, the inception of quantum mechanics has led to a divergence in the meanings behind the theories it brought about. These theories were similar in that they shared the same recognition for the observed phenomena and data recorded, yet the explanation behind them differ in terms of their take on the reality pertained to and their overall scientific virtue and honesty. In our scientific endeavors, our goal is to give objective meaning to the universe and its inner workings. However, we can realize that our human limitations may abstain us from reaching that total objectivity and leave us to models that our human capability can understand and use. In the birth of quantum mechanics, there is seen in whether those scientific theories were just models standing in for reality to provide us a way to understand what was occurring. More importantly, the influence that either of the two routes should be considered as we evaluate science in terms of our humanity. Perhaps, there is comfort in understanding an objectivity reality.

During the 1920s, quantum theory was accelerated through reapplication with the new theory in classical physicals. We can consider the entirety of quantum theory as one theory, during the time. This is because there were two sides debating its significance during the Solvay Conferences. As mentioned, on one hand, Einstein and his correspondents that the theory should follow the guidelines established by classical physics in that it was deterministic and grounded within reality. The theory would then be complete in all regards once the hidden variables were accounted for; variables that could be factored into a theory that predicted a phenomenon precisely. Given the newness of the quantum world, every aspect and measurement of it was not yet discovered and "hidden"; thus, the goal in completing the theory would to find all these undiscovered components.

Einstein strongly believed that a "creator" of the universe was kind enough to allow us to find the "truth" in creations and those creations shared the same reality with us. This philosophical viewpoint is heavily shown in his approach in thinking about science. His reach for hidden variable demonstrates that our understanding of our universe is limited by what we have not found. Essentially, we can grasp the mechanics of the universe to claim the levels it operates on. We may declare ourselves to be capable to understand the *creation*. This allows for us to exceed representations of phenomena once we obtain a deep enough understanding of them. Thus, his philosophy guides his claims and beliefs that reality should be real and deterministic. Einstein considered that theories and claims based on empirical data can be accepted as the reality, even if they are limited by human thought and capability. He went on to say that Bohr's interpretation was a quick solution for the scientific data and ideas at hand. These proposed theories were sufficient at the time to grasp the importance of the new field but only should act as temporary explanations until the real and true ones are found (Agassi, 2014).

On the other hand, notably, Bohr and some select others were on the other side of the quantum theory. Rather than a grasp on reality, the theory highlights the indeterministic framework of the quantum world. This framework resides on the fact that theory was statistical in nature and leads to either a conceptualization that reality is probabilistic or contained inside the theory itself as it only attempts to explain what is elsewise inexplainable or inconceivable by us. This new-found quantum world was a product of a new field of thought and rather to address newly discovered empirical date as compared to Einstein's approach (Stenholm, 2011). Some argue that a probabilistic approach to science is troublesome; that existence of other objects only occurs when we observe and measure them. That notion is supported by assigning probabilities to the states that we know and their relative existence to the others. The conception of science is that it describes and predicts our surroundings around us based on the reality it is in. This undermines that. These are the descriptors for the Copenhagen interpretation, strongly sided by Bohr. These ideas showcase a different mindset in its approach towards quantum theory. Most importantly, we must remember theories are an interpretation, a way to rationalize the presented conclusions.

It can be argued that even if the theory does not go far enough to encapsulate the reality of the universe, it can be successful in its aims as a theory if we allow it to do so in a defined context; it does not need to enclose complete totality of our universal experience. Bohr mentions that it is difficult to distinguish natural science from human-centric thoughts and influences (Stenholm, 2011). This implies that objective reality cannot be determined outside from human perspective. While this does not suggest that the reality determined by our human perspective is inaccurate (Einstein would argue that it is close enough to the objective real one, if not the real one), it is not enough for us to claim the behaviors and structures in science to be more than just models of that objective reality. There is then almost a dichotomy for one to choose. If one were to select or already find oneself in determinism and realism, Einstein's viewpoint is more plausible and sound. Science would be a way to accurately and fully go about and fulfill our natural curiosity about the universe. On the other hand, the Copenhagen interpretation as a model is the best approach to reality. Perhaps, science is only a tool for us to understand the universe to the best of our capacities. This implies that reality is subjective and that there is a separation between what we believe to be there and what is there. While there are many nuances between, this difference emerging from the "uniform" field of physics inspire the heated yet respectful debates between Einstein and Bohr over quantum theory and its completeness as a scientific theory (Agassi, 2014). We should also consider what both poles in defining science mean in terms of its acceptance in its truthfulness. Perhaps, these ideas behind the "virtue" of scientific theories can influence and lead to reflection of the way scientists proceed their work based on their held philosophical truths. In quantum mechanics, the theories may appear abstract, but we must consider their intention in the scientific information they contain.

A notable paper By Einstein, Podolsky, and Rosen arose in this field that is known as the EPR paradox. Here the writers propose a thought experiment that attempts to show the incompleteness of the Copenhagen interpretation. They describe particles can interact in a way that allows for the particles' velocity and position to be known simultaneously, despite Heisenberg's uncertainty principle. Suppose two particles start in a state that is relative to each other, possibly touching each other or entangled, then they have split apart. One particle's position is measured, and the other's velocity is measured;

so far, there is no violation of the Uncertainty Principle. However, using Conversation of Momentum from classical physics, we can compute the corresponding unknown property of either particle, leaving us with both particles' position and velocity known. This then demonstrates that the proposed method of thinking, in terms of Bohr's ideals, does not match the possible observables. This challenges the Copenhagen interpretation that orthogonal states cannot simultaneously be measured (Einstein et al, 1935). The other possibility voiced was in accordance to maintain that interpretation was the measurement of one particle instantaneously affected the state of the other. This had heavy implications in that this proposed interaction would have to occur faster than the speed of light which violates one of the tenets of classical physics, locality, and even more so, seemingly violated causality. Einstein coined this specific idea "spooky action at a distance" (Hacyen, 2006).

The authors mention that there is an objective reality that the physical aspects of the should theory correlate to its counterpart within that objective reality (Einstein et al, 1935). By having physical correlates, it assures that the theory is true in objective reality. Due to his belief about the nature of the quantum world, Einstein believed that a complete quantum theory forgoes this "spooky action at a distance" since it violates the core of locality in classical physics.

This arguably led to a series of experiments and scientific proceedings in understanding this "spooky action". Currently known as quantum entanglement - the relation and interaction between particles are even more nuanced for what Einstein and his collaborators than originally thought. It brings in concepts of non-locality and deterministic states which is philosophical troubling to some, yet it does provide an explanation and conceptualization of the phenomena.

The beginning of experiments in looking at the physical reality, as called by Einstein, would start with the Stern-Gerlach experiments. The experiment used an apparatus that deflected silver atoms using a magnetic field. Based on the magnetic moment of the atom as it entered the set field, it would be deflected an amount relative to that field. However, the results presented that the atoms were deflected to one of two locations, equal length from the “middle” and in exactly opposite direction. This lead to the conclusion that angular momentum or spin of the atom was quantized, more significantly, in the manner that Bohr predicted with the Copenhagen interpretation at the time. It showed that despite the entry of the atom into the field, it had only two choices in how its spin would be after it left the field. The outcome is best represented as a summation of the two possible states and is theoretically unknown until measured on its deflection location. Until it arrives at that location, the state it is in is unknown as it passes through the magnet. This is where realism comes to mind. We would like to think that it exists between the two options available to it. However, as it passes, we cannot definitively define its state outside of using probabilities, so the difficulty lies in allocating how it exists while maintaining that physical reality (experimental setup shown in Figure 1 where atoms are shot through a magnet and then observed on a surface). It is fair to say that conceptualization in those terms allow us to understand the function and significance of the experiment, although it may not approach the reality that experiment manipulates. The struggle is deciding which is better for a scientific theory to align with, as either side is philosophically driven (Wennerström, 2017).

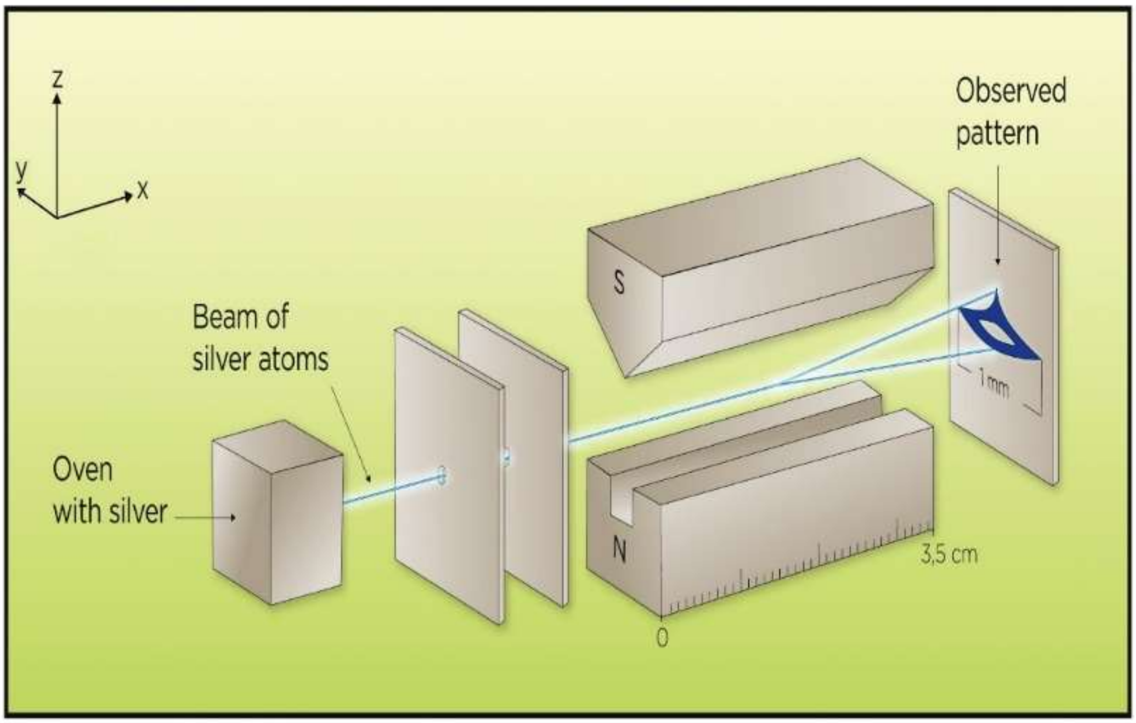

Figure 1. Stern-Gerlach Apparatus (Taken from Wennerström, 2017)

These experiments were repeated by many other physicists in the field. The name assigned to the “spooky action” was quantum entanglement. As quantum theory develops into to the modern age, other proponents are added, such as furthering Hidden Variable Theory and Bell’s inequalities. Physical experiments, some by Freedman/Clauser and Alain Aspect, show the phenomena executed under our control.

As technology has improved, experiments had been refined according to overcome experimental “loopholes”; they are locality and detection loopholes where each separate measurement is known after the instrument communicated and registered those measurements itself and uncertainty between paired measurements, respectively. They are due to the nature of the distance between the entangled particles when measurements are taken since the objective is to send them their separate ways (Bierhorst, 2014).

Early and modern experiments that attempt to replicate this phenomenon have a similar experimental design, yet properties can be varied. There is a source where paired particles can be produced and then split to send in opposite directions. They will then each encounter a polarizer which has preset orientation between the two for when then particles pass through. Each particle will then enter one of two detectors, an identical set of detectors is presented for both particles, and depending on the angle of polarization, the signals are simultaneously monitored by a single instrument (shown in Figure 2).

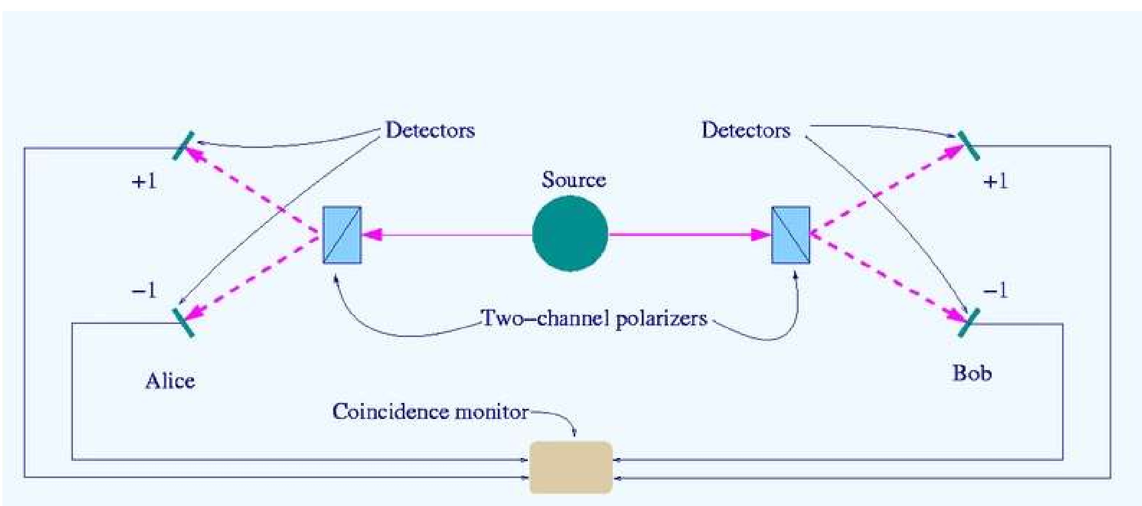

Figure 2. Clauser and Aspects Early Experimental Designs (Taken from Research Gate)

As predicted and found, the signal that is outputted is that the particles always enter different detectors, never corresponding one (Bierhorst, 2014). Like most scientific advancements, applications are considered. With quantum entanglement, the applications of quantum computing and encryption have been proposed and sought after utilizing entangled states after a pair departure (Wiseman, 2014).

Theory must be considered then when developing these applications. Arguably, applications have a direct handle on reality in that they are successful manipulations of reality. To change and control our world, we must fully understand the reality behind it and thus, if a theory does not serve as an exact mapping of reality, applications may not be argued. However, the other case we have is that theories are models but sufficient enough models that applications can still be created. Returning to the idea that theory is an apparatus, we have enough control over the apparatus to influence the entire system (reality) well enough in our motivations. Then, if there is no difference between the "virtue" of a theory for applications, the personal choice might be the greatest factor in aligning with a scientific theory.

With then proposed theories for entanglement, each offer certain axioms to define the quantum world and how we think about it. Each one brings their own philosophical implications. Multiple theories can explain the same data, from the extent as a model to a full description of reality. The philosophical themes mentioned in both are prominent but must be chosen carefully. The foundation of science lies in our philosophical separation from reality. Like Einstein and his realist correspondents, this foundation should approach our assumed objective reality. With that, we tend to accept their scientific philosophical ideals.

Chapter 4: Quantum Entanglement

Here we introduce the exact phenomenon that Einstein alluded to with his thought experiment, which was later named quantum entanglement by Schrodinger (Aspect, 1999). The explanation for the interactions of the seemingly physical correlates should be considered a scientific theory, defined within a certain frame and context. These theories are notable due to the tension between realism and locality, two philosophical themes that are embedded within quantum entanglement. We will see that we must choose to believe in one for the theory to uphold as theory directly mapping onto reality, but in the process, we give the other up. Bell's inequalities will show how we cannot have Einstein's local realism (Aspect, 2007).

The EPR paradox presented has been physically replicated with particles, such as electrons and photons with their angular momentum, and strong correlations have been found. Bohr asserted that the theory was complete while Einstein refuted stating that the theory was missing hidden variables. Einstein believed that the theory would only be complete once these variables are known. Quantum entanglement was heavily debated within the quantum community. These debates revolved around the reality that it represents on an epistemological basis. The themes that Einstein and Bohr found conflict over are based on the nature of quantum theory. Our ontological backing allows us to reject certain components of proposed theories or accept them in their entirety. This is important as we must consider the perspective we have on science.

To start, we can briefly summarize entanglement as correlated states between subatomic particles. These particles interact with each other and maintain physical states that cannot be described independently from the other. Most importantly, this state of being of the entangled particles is preserved at great distances (Nakhmanson, 2017). The entangled particles are usually directly attached or as one single entity initially, giving the entanglement. There are many processes in which particles are entangled or become so. An example is a nuclear decay, where the nucleus of an atom will decay into corresponding particles. Let us take the spin, derived from its angular momentum, of the nucleus to be zero, or having no spin. If the decay would lead to two particles and we would measure one's spin to find it to be spin up relatively, then the other would be spin down so that their total would be the original net spin of zero, all measured on the same axis (Harrison, 1999).

This is not all too surprising and even predicted by classical physics as it is just conversation of angular momentum. We can think of this by imagining a penny where it is cut through its center such that the head face is separated from the tails face. Each face is then separated. Each is put into two identical envelopes and are randomly given to two different people. Then those two people go their separate ways. At any point, one person can open their envelope and reveal to themselves and any other observers which side of the penny they have. Let us say that person A opens their envelope and sees the head side. This provides the trivial conclusion that they have the heads side, but it also importantly implies that the other person then has the tails side (Harrison, 2003).

The above analysis appears to simply require common sense. This is supported in the classical sense that each side of the penny exists when it is not being observed in that once it is put into the envelope and sent off randomly with one of the two people, it will remain as that side (heads or tails) inside the envelope in the person's possession wherever they take it. Even though they do not know which side they have, the side in their possession has an assigned definite value and remains that value after the initial separation. In a sense, all information about the system is known and real, whether we have seen who has which side. This realism provides us with the ability to claim that the side of the penny exists when it is concealed by the envelope and the action of the person opening the envelope does not change the side it is. There is also the implication that any action that would change the sides of the envelopes would not occur without the person noticing and there is no accidental "switch" of sides to occur.

While this may be an analogy, the two important philosophical items here are realism and locality. These align with our notion of reality since we tend to agree with the logic above in not only determining the side of the penny each person has but how it exists in those envelopes when being carried and not yet observed. We assumed that each side of the penny exists while being in the envelope. This existence refers to it being in one state from the possible two, decidedly when it is put into the envelope. The other significant assumption is that that is no interaction or perhaps a connection between the two sides after they have been separated from their original attached state. One cannot communicate any sort of information to the other, because well, they are sides of a penny.

A quantum approach in structuring this physical event presents a much different framework. Its aim is to meet is to relay the probabilistic information of the phenomena. It heavily relies on measurement to "collapse" the states of the particle. We can see that the reveal of the particles spin from a classical interpretation is deterministic in that it has already been decided before we even observe it. To then transfer that classical model to a quantum one makes that measurement of the spin indeterminant in that it has not been decided beforehand and that our measurement collapses or forces it to choose a state. In entanglement, the act of choosing one particle's state also chooses the other's. Probabilities are used to describe a state. Given one side of a penny can be either heads or tails, we can assign the side of the penny person A has 50% A and 50% B, and the same values for person B. It is not until the open their envelope that it then collapses to 100% A 0% B or vice versa. Consequentially, that person will then know what the other person has 100% certainty as well.

This again may seem trivial and similar, if not the same, to what was called the classical approach; the only difference is that probabilities were introduced. That being, probabilities are not much different from the concept behind the analogy. One can argue that it is like grabbing colored balls out of a bag, since the envelopes were randomly assigned, and we have an even fifty-fifty chance of receiving heads or tails from two envelopes. We must then consider that thought that the state of the coin is both heads and tails or neither heads or tails until measurement, depending what one's view of reality is. If reality is real, then the ball or side of the coin we grabbed is blue or heads and we just must look at it to find that knowledge for ourselves. However, if we struggle with that claim of reality, then the ball is green, blue, and red or none until we look at it. Once we look at it, we know which one it, at least until it leaves or sight or we understand how these apparently color changing balls work.

Let's say again that these entangled particles are separated by a distance where any interactions from Newton's and Maxwell's forces cannot be used to name interactions that occur between them, given their strength, distance, and time frame for experimentation. We can still accept that given an initial spin sum, the two resulting particles have spins of the same magnitude in opposite directions, despite the distance between them. This requires polarizers to be set up in a manner to measure the spin. For this case, two polarizers are set on the same axes to measure the entangled particles. This means that they will measure either spin up or spin down for the particles on the same axis meaning the particle only has a choice for spin up or spin down, relative to the chosen axis. Let's assume that we know one particle's spin, a spin up, we can conclude that we will measure spin down for the other, and that is true. However, let's say that we do not know anything about the particles, just that they are entangled through some event. They are separated at great distances at locations with the same polarizers set up. We do now know the spin of either of the particles, but we know that once one is measured by the polarizer, it would measure to be spin up or spin down so the particle is in a state of a fifty-fifty probability that it is spin up or down. We do not know which; it is random, to us and the particles, at least we believe so. This is because we have no knowledge of that particle outside of this scope. Once that seemingly random measurement is made, the state of the spin for that particle is determined. Consequentially, the spin for the other particle is determined as well. It is the opposite spin. The troubling item is that the state for that other particle before the measurement is considered that same probability and thus still random. This strong correlation between the entangled particles spin rises from seemingly two random events that are only decided by measurement. The particle should not know its spin until measured by the polarizer, and the other one should not definitely be known, yet it always comes out to be the opposite as if just separated. It is almost as if this measurement is collapsing the chances and then transmitting that new information to the other to make it a non-chance measurement; it is communicating for the other to make the opposite selection to preserve the initial entangled state.

As before, philosophical items arise again. Experiments had been done to show that the distance between the particles entails communication or interaction that exceeds the speed of light, which is against Einstein famous principle of relativistic causality (Wiseman, 2014). Also troubling is the notion that particles can have the ability to communicate with each other; opening another plane on the subatomic and quantum world (Aspect, 1999). Perhaps, it is best to not consider personification of particles now but instead explore deeper intrinsic properties of particles that are still unknown. Like hidden variables, that unknown set of properties can explain that “spooky action” leaving us still grounded in reality, albeit, unknown reality but still a reality. Another philosophical item is causality. Each particle, in this case, is necessarily identical in that the order that they are measured should not affect the system in that capacity. One measurement should not affect the other, in terms of probabilities, but it appears so in this case. If we make an action, then there is an effect and that action caused that effect.

Given our instruments, it is ambiguous to claim which particle measurement preceded the other (Wheeler, 1975). Causality is also up for philosophical debate in its place within the realm of science.

In the quantum system, probabilities are drawn and seen in experiments that the measurement of spin on one axis for one particle will lead to a probability distribution for measurements of spins on any axes for the other particle (Bierhorst, 2014). This is measured by exploring different angles set to the polarizers. The notable finding is that this probability distribution differs from the one calculated without any measurement, where it should be the same regardless for these entangled particles. This human-centric idea and action of measurement influence an event to occur that "supposedly" is centered in a non-human centric reality.

These probabilities we will find important as a famous physicist named John Bell would show mathematically that those probabilities from the spin measurements of the above particles should satisfy an inequality derived from classical logic. Like classical physics, classical logic is the basis of our deductive reasoning. It contains tenants that it abides by, although usually not explicit. With deductive reasoning, "common sense" stems from this form of logic too since both require base axioms to proceed forward in the thought process. Paradoxically, a proof using deductive reasoning by Godel showed that classical logic was incomplete (Harrison, 1999). Perhaps, this alludes another point to reconsider what our scientific conclusions and theories dictate. Another tenet is referred to as the "The Principle of Excluded Middle". In its simplest form, it is the claim that classical logic must result in a statement being either true or false and does not support that statement "existing" in between those two, hence excluded middle. In most cases, there are only two values, true and false, to apply to a statement and that statement must have one of those values. True and false, in this sense, follow the same definitions as they appear in other aspects of life. Another form of this principle is that the contrary of the statement cannot hold or exist simultaneously with the original statement. This is another approach in deciding true and false when ambiguity is present (Weingartner, 2011).

This logic is present in classical physics as they confine those fundamental laws about nature. They can restrict explanations for correlations found in fields of study. Logic can lead the way in deductive reasoning but can also hinder and stifle that deductive path; it can build barriers and limitations to where a theory can go if it does not adhere to that logic. There is a discrepancy between logic bounded inside thoughts and paper with the actual nature that surrounds us (Weingartner, 2011). There is a jump between that logical to classical physics, quantum theory, and scientific theory. That gap and the extension of the said gap would reveal how much comfort we have in our conclusions about reality. Our logic is considered enough to breach the gap. It has been mentioned that we used deductive reasoning to arrive at our conclusions. However, we cannot forget inductive logic, a huge proponent of scientific theory and perhaps the defining path to it. Our ability to form that bridge using surrounding materials on the observable side to reach the reality side where the "truth" is. However, it does go to say that it contains a huge major fallacy.

A popular illustration of that flaw by logicians is called the Scientific Drinker. The Scientific Drinker was “fond of alcohol” such that they got drunk every night of the week. This is obviously having a detrimental effect on their health so in realizing that, they vowed to fix their health by devising an experiment to discover the cause. They first concluded they felt the worse at night after visiting the bar and begin the experiment there. They asked for their usual scotch and soda, and by the end of the night observed the effects to his health; unsurprisingly, they were negative. They go on to repeat this process the rest of the week; they drink bourbon and soda the next day, followed by brandy and soda, then gin and soda, and finally rum and soda each with the same negative consequences. The Scientific Drinker using inductive reasoning arrived at the obvious conclusion; they would never drink soda again (Adapted from Copi, 1961).

While that highlights the biggest problem with inductive reasoning, it is difficult to avoid just purely based on our gap of knowledge and known “truths” of the universe (Weingartner, 2011). Thus, we return to our central problem in discovering the way to best comprehend the scientific theory of quantum entanglement. Theories drawn up inductively do not resemble reality yet can stand to understand the nature of the phenomenon at hand. A theory of quantum entanglement could be the “soda” to the drinking problem and yet maintained under valid inductive reasoning. The theory that is now held by the Scientific Drinker is to never go to the bar and drink alcohol and soda again, and every time that is upheld, they will never feel sick. We see that theory offer an explanation that is not fully representative of reality, but it maintains its ideals with a sense of understanding in that frame.

All the principles and themes presented have a place in science, or on the other hand, do not or need reconsideration in how they are placed within the place, given the finds on quantum theory. We relate classical logic to thinking about the penny's sides or particles. Let's consider the statements that

1. Person A has the heads side of the penny
2. Person A has the tails side of the penny

We see that statement 2 is a negation of statement 1 in the context of the pennies. If a statement is not true, then it is false. Both statements cannot be true since person A can only have one side of the penny. Trivial, choosing which statement is true is not difficult once that envelope is open. The difficulty lies when the envelope is closed. Surely logic still must apply in this case; it should not be on break. Statement one is somewhat true because it could be heads, but the same logic applies to statement two. We have the same dilemma as earlier as we either conclude that we have both statements simultaneously being sort of true or sort of both simultaneously being false. This "sort of" true or false puts us in the excluded middle that logic is purposely trying to avoid. Arguably, the validity of logic is compromised so either we choose not to believe our logic is flawed for this purpose or alternatively, form new rules for logic.

Another approach would be to consider Kant's opinion through his principle of complete determinism. It aligns with that one considers an object determinate and the state that it is in to be determinate as well. It follows nicely with ideas of realism and determinism. The principle makes an if and only if statement, meaning the reverse is also true, in that observables are real and determinate if and only if the totality of the experience is also real and determinate (Stang, 2012). This meaning that the context in which the involved objects are in must be considered real and determinate. It cannot be said that only one or the other is within reality. If we assume for the states to real, then reality is also real. However, if we were to think about the states as indeterminate, we cannot say the reality that is part of to be determinate, leaving us at a strange place for conclusions about reality. These opposing views on science appear to affect scientific ideals, showcased by Einstein and Bohr. Yet, the results of the science remain unchanged but different perspectives should present some altercations and ambiguities on the science at hand.

The last important parameter to further examine is measurement. Heisenberg stated that "the path of the electron comes into existence only when we observe it" (Harrison, 1999). We have all heard the thought experiment of the philosophical tree falling in the forest. If no one is around to hear the consequential sound it makes with an impact to the ground, does it make that sound? Similarly, we can make the comparison that if a phenomenon happened, and there's no observation of it, are we allow to classify within our realm of science? Another consideration is the effects of measurement on the observable. In many of the sciences, this effect has been decided has had minimal effect on the actual results of the measurement (Harrison, 1999). Some scientists do strongly believe that the measurement causes a significant disturbance to what is being measured, and thus the resulting expressions. An example would be a scientist studying a group of animals in their untouched, natural state. The assumption is that their presence would not influence the behavior of the animal group. After further inspection, all the measurements turned out to be their behavior when it knew it was being observed by the scientist.

This returns us to another yet philosophical debatable item of quantum theory and complete evaluation of a theory. That item is the assignment of consciousness to these electrons that appear to be aware of not only each other but also us. Why do we even care about if they do care about us, and is it even our place to do so? This is the troubling question for an explanation of entanglement. Are we allowed access to that depth of the universe? Quantum entanglement proposes empirical evidence that leads to these questions in which the answers allow us to choose whether we can see it as a model or indicative of reality. Those answers are heavily dependent on the strength of our grip on realism. We see the realism is paired with a full understanding of reality.

Chapter 5: Hidden Variables

For Einstein, his philosophical nature did not allow for him to simply give up the concepts of realism, determinism, and separability. He argues that the universe was much more complex in its outcome than rolling dice. However, there was a growing divide between determinism and the field of physics, which has never occurred before (Vella, 2002). This newly found quantum theory was a response to explaining quantum entanglement was importantly philosophical sound to Einstein and invite these problematic and troubling notions in. Einstein didn't quarrel with the results coming from the predictions of quantum theory, but rather, he had issues with the reasoning behind it and perhaps a refusal to put the interworking of the universe under that proposals. We see that his explanation for quantum entanglement largely derived from his scientific framework which does not change the phenomena but passes onto us his concept of reality.

Einstein argued that quantum theory was incomplete and devised a framework of for theories, known as Hidden Variables theories, to demonstrate that it was. He argued that when these hidden variables would be accounted for, it would produce the same results as quantum theory dictates but more importantly show the incompleteness of quantum theory in that these hidden variables account for the "spooky action at a distance" as well as explain the statistical and indeterministic nature. This was relieving in that it restored determinism in that it became a classical physics problem; the behavior that we are most familiar with and understand its mode of operation the most. Given all the variables and their relations, anyone could predict the outcome to the dime. To showcase this, we use an analogy to a cannon shooting cannonballs, a very common physics problem.

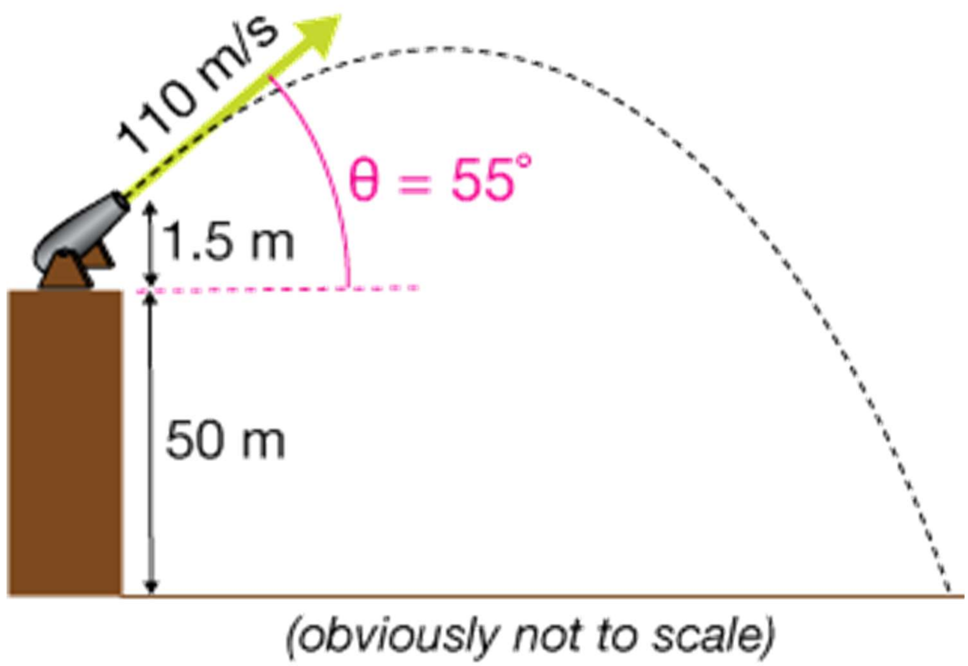

Figure 3. Classical physics problem (Taken from xaktly.com)

We may recall that provided with the annotated numbers for the variables above, we can calculate the trajectory and destination of the cannonball as shot by the cannon using Newton's laws; nothing too groundbreaking here. This is possible due to the natural relations between the variables as they interact with one another to determine the location and velocity of the cannonball after it leaves the cannon. Most importantly, given the same conditions and variables, the cannonball will always follow the same exact path and land on the ground in the same exact place. This is all true, in the realm of the physics problem.

We can imagine this same setup being done realistically. Surprisingly, or unsurprisingly, this reality-based set up would produce differing results. We would find that all the cannon balls would not land in the same exact location nor follow the same exact trajectory. However, if we were to trace the paths or mark all the landing locations of the cannonball, we would find that all the paths and landing spots are relatively in the same proximity. This is expected by real-life application of physics. The explanation is also very philosophically sound and does not expose any holes in our logic and understanding of the world. The cannon balls do not replicate the exact trajectory, even though the cannon setup and variables remain unchanged because the relations describe by classical physics are not fully complete and have variables uncounted for, at least in this crude example. It does not imply that sense of indeterminism with our classical physics framework or strange causal relations. This apparent probability distribution of the cannonballs landing locations is the lack of consideration for all contributing variables. Thus, a total incorporation of all variables would "restore" determinism in our explanation of varied trajectories. We know that there are other variables such as wind speeds and air resistance that affect the cannonball in its motion that is not held constant or accounted for in this model. However, and most importantly, if all these variables were known, the model positioned in real life would behave such as in a textbook problem where all calculations will exactly predict deterministically the futures of the cannonballs (Adapted from Jean, 2016).

Again, this showcased the mindset that governs classical physics. As a collective, we found and perhaps designed an understanding of our world and within this world. We found and established relations between forces and entities surrounding us. These are the lines that guide the assumptions of classical physics. Based on relations we have derived previously if we were to know every part of that relationship except for one missing variable, we could solve it using the others. This displays how we conform to reality (Mackinnon, 2010). Logically, if we were to calculate a relation for a missing part with all the known other variables known and arrive at an unexpected result, we can conclude that there are missing variables. Since Einstein strongly believed in these principals for physics and the universe, this explanation was the appropriate one. It explained the results of quantum theory with missing variables, avoiding the “spooky action” approach. Reasonably, there are simply some things we do not yet know about the universe that may greatly contribute to understanding this quantum world. As Einstein hopes, once we find these hidden variables, a full derivation and explanation will come to light (Bacciagaluppi & Valentini, 2013).

This restoration of the physical world being deterministic was again another offering in explaining what was observed. In respects to quantum entanglement, the phenomena that were devised through EPR’s thought experiment, showed that hidden variables could be behind it, or at least an explanation. The particles involved in entanglement seemingly “communicate” with each other instantaneously after measurement of one of their positions and momentums are known better than Heisenberg’s uncertainty principle allows for. Thus, the explanation of transmitting information about those properties to one another is returned. Aside from particles "communicating" and "actualizing" measurement, this entails especially for Einstein, that this interaction is occurring faster than the speed of light, which violates relativity, a theory conveniently found through him. Philosophically and scientifically, this violated locality too as all physical interactions must travel through space and time. To get from point A to point B, the space between the two has been somehow traversing through eventually. One attempt, as many others, constructs these hidden variables, based in time and space, to solely mathematically demonstrate how it aligns with Stern-Gerlach experiments and wavefunctions as well as to offer experimental approaches in locating them (Brodat, 2016). On the other hand, these hidden variables are just underlying currently inaccessible values or probabilities that fix and adjust quantum observables, applicable to the entire theory (Bacciagaluppi & Crull, 2009). Most importantly, the thought that such mathematical constants or elements of reality existed would keep determinism and bring the universe back into a textbook problem.

There could be such guiding influential variables that are unaccounted for in our reality and universe. In explaining quantum theory, this is one of the considerations for an explanation. The philosophical conundrum is that regardless of its actual presence in these matters, our belief in it does not affect the resulting phenomena of quantum entanglement. It returns us to the idea that our human thoughts and expectations influence the reality that surrounds us. We see that there has been a divide on quantum entanglement. Not on the actual measurements or observables, but the causality behind it; more specifically, the term we call science and the "virtue" behind them. Our interpretations and perspectives strongly influence our inferences as they lead and direct those necessary gaps between gaps of knowledge.

Deterministic and causal models have been proposed, such as Einstein envisioned, for entanglement with classical analogs (Cour, 2014). Einstein even had his own manuscript for his hidden variable theory that preserves determinism in response to Bohr, Heisenberg, and Born, yet it was unpublished (Belousek, 1996). On the other hand, from the other three, the indeterministic and probabilistic description of such phenomena is the "full picture", that there was nothing hidden or uncovered. The model was complete, but in that, it was just a model and that was as good as it was going to get.

Many share this pursuit that Einstein maintained throughout his discoveries; reality is there for just to uncover. Thus, the quantum theory should be more than a model and we see hidden variables addressing a full description. Ultimately, that should be the goal of science. This causes problems as we will see as mathematician named John von Neumann proved that there could not be hidden variables in quantum entanglement. Both cases were not completely correct as mathematician and physicist named John Bell brought a significant contribution to the debate (Bub, 2010). He provided insight into how quantum entanglement further nuances the nature of a scientific theory by forcing us to re-evaluate our position on realism.

Chapter 6: Bell's Theorem

The philosophical backings of quantum theory were debated in whether its nature was deterministic or probabilistic, local or non-local, and causal or non-causal. As mentioned, the dividing proposal for determinism in quantum entanglement was the call for hidden variables. This presentation paved ways for many theories explaining quantum entanglement on that basis and kept these theories grounded in reality. John von Neumann was thought to prove and conclude that there were no hidden variables forgotten from the holistic quantum description. However not too long from that conclusion, a Northern Irish physicist named John Bell logically proved that the correlations found in quantum entanglement cannot be from the local cause. These interactions would have to violate our sense of locality and causality. This was different from von Neumann's proof as it did not completely rule out hidden variables. It stated that if there were hidden variables, they were non-local and only if one did believe in the idea and concept of them. Non-locality hidden variables and interactions implied the philosophical surrender of those two ideals. While it maintained a deterministic sense, this surrender was most notably opposing Einstein's principle of relativistic causality (Wiseman, 2014). This states that causal influences or communication cannot propagate faster than the speed of light. We think of this causal relationship as one event must occur first and then travel some distance to trigger the second event that is linked because of the first one (Aspect, 2007).

There is an axiom of causality in which if an event is seen to depend statistically on a freely chosen action, then that action is a cause of that event (Wiseman, 2014). We can imagine a switch here on Earth in our house that is somehow connected to a light bulb exactly on the other side of the world. Suppose we somehow had the ability to observe both locations at once in parallel real time. We then flip the switch on. Here, we expect to have some delay between the action of flipping the switch on and then the light bulb lighting up, also supposing that we can observe in the relative time frame. We know that the act of flipping the switch is directly connected and causes for the light bulb to turn on. In our experimental entanglement measurements, it is found that resulting correlation is uncanny and has been repeated many times over different experiments (Hensen et al, 2015). It leads us to a crossroads where there are interactions that propagate faster than the speed of light or propagate non-locally. The latter holds on to determinism as hidden variables are responsible for this non-local interaction while the former perhaps invites many other notions. These notions consist of faster than light communication and causal influences to remain locally (Shalm et al, 2015). Locality is an important issue as it has been an uncontested philosophical ideal within classical physics; waves and particles must move through time and space and that movement is usually cause and effect.

Here again, we arrive at a place in science in which the problems with the truth arises. This truth is our mapping onto reality. We are presented an intersection in deciding the explanation for this event. First, let us take Einstein stance in that the universe is not a casino and that are deterministic events due to causality which must occur locally. As we then see the results and implications of quantum entanglement, deterministic events are instead called to be probabilistic. The conflict here is whether the nature of the universe is deterministic or not. Perhaps, quantum theory is just a model and apparatus to provide us with an understanding of the universe that fits the outcomes we observe when it is purely deterministic. It is difficult to perceive what a probabilistic universe would entail but conversely, it is easy to calculate for one. Then is the truth in science merely a way for us to conceptualize the universe or an actual extrapolation and mapping onto reality? Are we playing with models or the real deal; more, importantly, does it matter which one? The answer to that is found in our philosophical nature and our orientation within this universe. Ignorance and knowledge both have their stakes in our satisfaction. Are we content that our universe can be simplified down to an algebraic concept or does that algebraic somehow completely embodies the universe?

In returning to Bell, he offers a concise way to tackle that issue arising from entanglement. He does this through a mathematical proof that only requires two assumptions that are seemingly very general. They are:

1. Logic is valid
2. Parameters exist whether they are measured or not

From here, Bell was able to develop an inequality that becomes very applicable. It is:

The number of entities that have state A but not state B plus the number of entities which have state B but not state C is greater than or equal to the number of entities which have state A but not state C.

Or more mathematically:

Number of states (A, not B) + Number of states (B, not C) $\geq$ Number of states (A, not C) (Taken from Bell, 1964)

This inequality should hold for all things, just not the particles of quantum entanglement. Let's suppose that we choose the states to be (and assume that a person could also be any combination of the states):

A: Regis student B: Regis faculty C: Jesuit

So, the inequality reads "the number of Regis students that are not faculty plus the number of Regis faculty that are not Jesuit are greater than or equal to the number of Regis students that are not Jesuit." We see that the right-hand side of the above inequality is a subset of the union of the other side so that the number on the left will always be greater than or equal to for any case. Interestingly in cases that the inequality does not hold it, we can use a proof by contradiction that leads us to our assumptions being false (Adapted from Harrison, 1999).

We return to using Bell's inequality in the realm of quantum mechanics. Let us suppose that we have photons for our entities. We then shoot these photons in a ray of light through polarized lens, in which the wave motion of the photons moving in the electromagnetic field then only move on one plane after it passes through the polarizer. These photons' nature dictates them to either move through the polarizer completely or is blocked, as quantum theory entails. As quantum theory describes, this interaction is of statistical nature in that the photon has 50% chance of passing through and the other 50% of not passing through. We are unsure of its passing until it has gone through the polarizer, as there is no deterministic way to calculate its passing. It can perhaps hold an unseen hidden variable that lets the particle know if it is able to pass or not.

For this experiment, we set up polarizers in series so that the particles can pass through them both. Let's set both polarizers are the same relative angle of 0 degrees. It has been found that the photon will 100% of the time passed through both. However, let's set the first at 0 degrees and then the following one at 90 degrees. It is then found that 0% of the photon will then pass through. Unsurprisingly, when the second is set to 45 degrees, 50% of the photons will pass through allowing for a correlation to be drawn between the probabilities and angle difference. One may assume that this will be a relationship defined by $\cos^2(\theta)$, but once the difference is 22.5 degrees (half of 45 degrees) it is found that 85% of the particles make it. This higher resulted value does call for some attention. We then insert the polarizer at 22.5 degrees between the 0 and 45. This then mathematically calls for 85% of the photons getting through the second polarizer and the same percentage again after the final polarizer: .85 * .85 = .7225.

However, when the second polarizer was not present, only .5 of the total initial photons made it through. This implies that with more polarizers, which purpose is to filter light, more light will pass through (Bednorz, 2003). On a more philosophical basis, it also calls again to the question of what does allow for the photon to pass through. We have demonstrated probabilities, yet there is not a true derivation of where such probabilities do come from. The universe may partake in deciding such values. If that is the case, science is purely dependent on that conscious decision. Does our awareness of the universe intersect with its awareness of us? This is an explanation for the observed, but it is not the only one.

We move on to how this refutes hidden variables as we have our series of polarizers for our photons to travel through. In retaining hidden variables and determinism. The photon would have already decided which of the three it would and would not pass through way before we ever take the time to measure it and find out. Let's go with our initial assumptions in Bell's inequality with the addition of a third one that we have discussed earlier. They are:

1. Logic holds
2. Reality exists without our observation
3. Interactions are local

From here, we assume that the photons know which polarizers they will pass through before they are shot through decided by their hidden variables. The photons are all shot through and they all pass through the first polarizer as expected (0 degrees). From earlier, we see that 85% of the photons pass through the second polarizer (set 22.5 degrees from the first one); thus, 85% have a hidden variable that allows for them to pass through the second one. Thus, so far, we have Number of photons (A, not B) = .15 and Number of photons (A, and B) =.85. Next, the photons face the third polarizer in which 85% of the remaining photons pass through. Now, we still have Number of photons (A, not B, not C) =.15 but in Number of photons (A, and B, not C) = .15*.85=.1275. As earlier, the rest make up for .7225 that pass through and have the hidden variable for all three polarizers. Yet, in the case with only the front and back polarizer, only 50% make it through even though 72.25% of the photons have the hidden variable to make it through both.

Let's look at Bell inequality which should hold true in the case the hidden variable needed to pass through the polarizer is just considered a state algebraically.

A: first polarizer (0 degree)

B: second polarizer (22.5 degree)

C: third polarizer (45 degree)

Number of photons (A, not B) = .15

Number of photons (B, not C) = .15

Number of photons (A, not C) = .5

Number (A, not B) + Number (B, not C) $\geq$ Number (A, not C)

$.15 + .15 \geq .5$

However, .3 is not greater than or equal then .5 and thus, Bell's inequality is violated and now we have a contradiction. According to math formalism, contradiction shows that one of our assumptions is wrong. It cannot be our first one that logic is valid because that would also disapprove our conclusion to this point, along with many other troubling items. We then move to our second assumption that states are definitive at points when they are not measured, also known as realism. Yet if this assumption was incorrect, it does provide an explanation. The photon not having a definitive state until it is measured by passing through the polarizer would support the probabilistic nature and that the photon does not have any already made decisions as it approaches the polarizers. In fact, it does not exist in any state, but rather in a probability of states. This may be hard to fathom but this proposed reality may only exist in our science as it serves as the best method to understanding the photon behavior, whereas the true reality may be completely far off. It seems that our human measurement brings it into reality, and who's to say we have that great of influence over the universe?

These experiments have been done over a great length where any communication would exceed the speed of light. Here we visit our third assumption of locality. It is possible that every passing of the polarizers changes the state of the photons hidden variables. This setup does not have the polarizers in series but separated so that entangled particles pass through at the same time. Entangled particles shared the same resulting passage of polarizers orientated in the same way at great distances. The experiment is then choosing a random angle for both separated polarizers (between the choices of 0, 22.5, 45 degrees); the same correlations and probabilities are found for these states and entangled pairs. So, if these particles have definitive states and we believe that each measurement changes the hidden variables, we must give up locality and turn to non-local hidden variables as the same violation of Bell's inequality implies there is some interaction between the entangled particle to derive this correlation.

With our assumptions, one of them must not be true and again, we reach a divide in which we must take a path in which we accept realism and forego locality or the exact opposite.

Chapter 7: Bohm's theory

An important part of the experiments relating to quantum entanglement revolves around the ability to observe and record measurements. Measurements are important in also judging and evaluating scientific theories. Measurement provides us with a great deal of insight in relating science to the reality of the universe. It showcases our approach to understanding it and our thoughts on its entirety; it shows what we really think is true about reality and how our natural philosophy must govern those choices into acceptances. Measurements build a composite understanding and view of reality that we can live contently alongside.

Our ability to observe phenomena such as quantum entanglement is an inherent trait we all have. With this, our simple act of observing influences the universe; this assumes that we do have a significant value to the universe. As we saw from entanglement, our observations and measurements of the particles produce results in where it seems like the particles themselves are aware of us, like how a pet animal may be aware of its caretaker (Harrison, 1999). The animal may never exhibit its natural behavior in the presence of its caretaker's observation, alike to the particle in its existence in the universe. Thus, it could be our measurement gives it the behavior we observe. With realism, this creates a conceptualization in which the particle does not exist outside of it. It exists as an entity, just not what we conceptualize a particle to be. The fear is then the validity of science in that its common aim is to give us information about the universe, while instead, it may only be information our interactions with the universe. This greatly changes our perception of scientific theory as just models for our own sake as we would never know a reality outside of our human one.

With entanglement, measurement is further complicated due to the inherit size of particles. The notion that the particle is between states when it is not measured could be purely for understanding and a way to address the probabilities that result when applying many measurements in examining its current state. Yet, let's suppose that it does exist in this probabilistic conceptualization and that us measuring it provides it definitive property. Now we are more than just measuring it, rather, we're providing our inputs and participating in the events of the universe. Us, as participators, are created from the universe bestowing some power onto us that lets us create theories and with that ability, we then ourselves provide meaning to the universe in return (Wheeler, 1975). When we are looking about into the universe, we are just looking into a gigantic mirror. Bohm says this more concisely, as "[Through the] mirror [of quantum physics] the observer sees [themselves] both physically and mentally in the larger setting of the universe as a whole… More broadly one could say that through the human being, the universe is making a mirror to observe itself." (Bohm, 1981).

Other proposed theories for quantum entanglement and different mechanics that attempt to explain results from conducted experiments in the same vein as quantum mechanics do. They have even emerged in the same time frame as quantum theory did. A more notable one would be what is now considered Bohmian mechanics; it stands out because it addresses all the quantum philosophical gaps while still offering an acceptable "scientific" explanation. Its emergence is attributed to de Broglie and he called it Pilotwave theory. He proposed that there are guiding waves whose surfaces of equal phase that a freely moving body follows orthogonally as a replacement for Newton's first law of motion. However, it was heavily criticized by his contemporaries due to many coinciding attributes and simply abandoned. It was not until decades later until Bohn picked up its remembrances (Bacciagaluppi & Valentini, 2013).

Bohm re-interpreted the theory into his own ontology. He uses an example of a TV to express his direction with this theory. He models that TVs display two-dimensional projections of a three-dimensional reality, yet the actual reality of the three-dimensional space could be nowhere close to the projections. Thus, the observed particles could be projections of a higher-dimensional reality (Bohm, 1980). This developed into a quantum term referred to as the quantum potential and in mathematical and realistic expressions, a mechanism that is non-local to hold causality (Bohm, 1993). In quantum theory, the notion was that when an object was not observed, it is in all possible states that it has the option to be in and this is written as a superposition. Its existence in this superposition state conflicts with the idea of realism, that items have definitive states when not observed. It implies that when we are not in observation of other entities, they seemingly do not exist in the definitive states we think them to be. It must be conceded that this does often refer to subatomic particles; however, there is a significant amount of them in the universe. These superpositions do not fail though as they always make the right prediction from experiments throughout this century that tests properties of these subatomic particles, which classical physics did not provide a complete answer to. To an extent, quantum theory is accepted because of this factual evidence, although along with it, it brings problems with determinism, measurement, realism, and localism.

Opposing, Bohmian mechanics' quantum potential can be imagined as an underlying field that guides the path of particles deterministically. It respects Bell's inequality as the field is non-local where a location of where the particle is can be affected or affect a location somewhere else on the field instantaneously (Harrison, 1999). We demonstrate this comparatively to quantum mechanics using the double slit experiment. The double slit experiment served as a physical anomaly due to its produced results. It shot electrons through two adjacent slits, with the capability for the electron to go through either one and then recorded the locations where the electrons ended up landing on a surface directly behind the slits. We expect to find the electrons in two locations, both directly behind the respective slit that they passed through. However, the results were much different. The electrons ended up producing a pattern on the surface that would be explained by each particle passing through both slits and interfering with itself. The response to this confounding result was by setting up the experiment again but with doors that randomly alternate between having one slit open and the other closed. With this, the originally expected pattern was found. Quantum mechanics conceptualizes this occurrence by claiming that it goes through both doors which allows it to interfere with itself because it has those two options. Once we collapse the superposition state or provide it with only one choice, it then only passes through one door (Bohm, 1993). It is possible that the electron only ever does pass through one slit, yet superposition best explains the experimental results as it passes through both slits. Bohmian mechanics let us keep the electron as a real entity that only passes through one slit; one particle always in one state.

This separate theory shows that it can explain all possible experiments as well in this realm. For the double slit experiment, it is derived that the particle must have a single path from its ejection through a single slit and onto the behind surface. This is necessary to preserve determinism and realism, whereas, in quantum mechanics, the particle seemingly takes every possible path, leaning towards indeterminism and non-realism. Bohm also claimed that given our technology, the particles ejected never truly start out in the same exact location, and thus a different path, although spatially close, is then taken by that particle (Bohm, 1993). This is a reminiscence of our textbook classical physics problem where there are missing variables. Bohm knew that this was a hidden variable theory that Einstein was searching for. This also implies that the theory is deterministic, a theory that is more comfortable in a sense that it is an actual representation of reality and can be traced to reality. The slits then have values of “open” and “closed” in their contribution to the quantum potential. This then changes the field in which the electron would travel on, thus explaining the differing results in the original and the modified experiment (Harrison, 1999).

While this brings determinism back, it does not bring it back to the point of classical physics. The implies that this underlying field in its entirety covers the universe and affects a single particle all at once with non-local interactions. While determinism is important to classical physics, localism ranks at the same level.

Another related experiment with the double slit was conducted to examine the measurement problem. Sensors were attached to each slit so that when the electron passed, the sensors would pick it up. From quantum mechanics, it states that then both sensors would light up. Yet physically, only one did at a time. This brings back our debate on the particles recognizing our measurements to then collapse to choosing one slit and one path. Overall, the sum of all trials does not produce that. Bohmian mechanics again offers a way to reconcile this without providing particles a consciousness. The sensor measures one particle going through one slit (Bohm, 1993). For entanglement, the particles can interact with each other using this quantum potential to produce the correlations we have seen. This non-local ability to interact or to decidedly express a singular state of existence by having one particle measured will instantaneously affect the other indefinitely further away (Rosaler, 2015).

This quantum potential seems contrived in a creation of a new term and plane. We can argue that quantum mechanics is contrived to some degree as it attempts to explain phenomena such as quantum entanglement because it seems tailored to the experimental results. Theories would not be required if every element of the universe could be and willingly measured. Again, we have a theory of quantum entanglement that appears fitted to our experiments but is rather stemming from our philosophical acceptance. A true notion of reality may be important to some so working to develop explanations for that preservation has a sense of urgency because science should be a direct mapping of reality to maintain that we must give up locality to preserve realism.

Chapter 8: Conclusions

Science is deemed integral to our human society. Science offers a realm that is perceived to provide truth to the universe since it gives us to manipulate that scientific gain in applications. It makes sense that our ability to apply that knowledge implies an understanding of its conceptual true being. However, in the scope of this thesis, science found here is more focused on those mechanical interactions at one of the lowest divisions of matter, referred to as particles. These particles are present within our notion of the universe, and thus a holistic understanding of them would provide immense insight then to the "truth" behind the universe.

The important item to note here is this is with *our* notion of the universe. While science is assumed to be relativity objective, it does have a subjective nature as demonstrated through scientific theories. While we may discover concrete properties about natural phenomena, a connection that attains to said properties need to follow as well. An explanation for these items is important to us as humans because it removes the mysterious and vast nature of our surroundings and the universe. This explanation does not have to be representative of the truth. An explanation or theory that is comfortable and sound enough to be accepted can pass by and be upheld if it aligns with the empirical evidence and follows some sort of logic that is supported by others. Science has theories in this vein throughout humanity from earlier times when the solar system was thought to revolve around the Earth. Calculations based on celestial bodies made for navigation still allowed explorers to get to their desired locations. Religious influence and affiliation also allowed us to think that the Earth existed as the universal pivot as a said creator intended. As we know, this was first denounced later by Kepler in which the explanation was that then the Earth revolved around a star. Surprisingly, the calculations for navigation remain constant amidst this new change in “truth”.

Quantum mechanics, a relatively new field that stems from classical physics, attempts to explain forces and interactions between these subatomic entities. It offered new ways to interpret and represent already defined theories. With some mathematics, it was able to produce the same results. The stark change that resides with quantum mechanics were new philosophical concepts in which on how the science was looked. It brought in ideas of realism, localism, and determinism to provide an explanation for the phenomena and questions it was attempting to answer. Specifically, quantum entanglement was the biggest phenomena in this philosophically-disturbing room. Quantum entanglement showcased the interactions between two linked particles in which the interactions are shown and measured lead to conclusions that did not align with the tenets of classical physics.

These tenets preserved theories that were thought to be static and completely defined for the time; these pairs of particles poked holes in the philosophical groundings of those tenets. It implied that particles’ states were indeterministic and that it does not exist in a state until it was observed by human eyes. Those poses very philosophical disturbances in imagining existence without observation. It also calls our significance to the universe in the implication that our human existence provides existence for these entities; surely, particles have other things to worry about than us. Another explanation for entanglement in which guarantees the existence of non-sentient particles is for there to be some interaction prorogating faster than the speed of light. However, Einstein would not agree as it violates his theories and concedes localism; interactions must travel to space and time.

Theories, such as Bohm, have arisen in tackling those philosophical items while maintaining the phenomena. Bohm proposes a quantum potential that restores ideas of determinism in that the particle is a point in space but still must give up locality later shown by Bell's inequality. This is an example of a hidden variable theorem, as Einstein predicted, was the solution to these concessions of philosophical items. A reasonable approach was that we were still missing fundamental proponents of our framework to the universe and when these would be discovered, classical physics would still serve as the basis for these new variables added.

Notably, these theories that are proposed could very well be some explanation that does not touch the objective reality of the universe at all. They serve as models since they offer a conceptualization of the seemingly real observables we interact with. However, it is fair to say that we are striving to find the truth within all of this. The debate is then in distinguishing between the two; this appears to be done through the abstract of ideas and again the philosophical grounds we cannot let go of. Bohr even said that quantum mechanics was just a way to explain the observed phenomena in an understandable way and do not directly map onto reality (Bacciagaluppi & Valentini, 2013). It could be that the true mapping of reality into our science is even more abstract and incomparable. Again, either adoption may not influence a scientist moving forward with their experiments and publications. However, it might very well affect their conclusions and logical proceedings.

In any case, scientific theories should, in nature, attempt to directly address reality because that is science's initial aim and true intent. Models may be useful and even solutions for our understanding of complex phenomena, but they are temporary in our quest for a holistic understanding of reality. Even when a model is in place, further research is still undergoing to reach that complete and absolute view of reality. Some may be content with models, but with that contentment, there is an acknowledgment still for the greater background reality. Thus, there is a satisfaction in discovering what lies in the entire system behind our models and apparatuses.

Since this is our view of scientific theories and reality, we then must give up locality over realism considering quantum entanglement. This is the selected choice as realism and an understanding of reality are staggered upon each other. It is fair to claim that our current concept of reality is wrong and does not revolve around the philosophical ideal realism; however, much of our basis of knowledge relies on the definite existence of objects without our direct observations. Thus, it is easier and simpler to concede locality, as pressured by quantum entanglement. For Bell, this was a solution to the problem as he proposed to keep deterministic hidden variables if there is a concession of localism, rather than reject that idea of hidden variables in totality. Bohm went on to develop that idea into a well thought out scientific theory since there must be a reality that is "real" by our standards. Giving up locality allows us to not fall back into models as we have a sense of a description past that and again, that should be the true aim of science. Interestingly, it forces us back to relook at other theories without this notion of locality.

On the other hand, one can reside in entanglement being a model of reality strictly on their philosophical conceptualization of reality. However, this debate is positive rather than negative. Science exceeds past than just a field of study unraveling the truth behind the universe; it involves our conscience efforts and evolves differently due to that. This entanglement of the truth does not open in one singular way. We can accept that theories are simply models but hope that they reflect the reality around us. They may, and this allows us to be selective in the ideologies that entanglement places on us. Our view of the universe reflects the strength of science's mapping onto reality.

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