ỌRÚMILÀ NÍ ÓÒ WÀÁ BÁ NÍ : EXAMINING THE QUANTUM MEASUREMENT PROBLEM THROUGH THE YORUBA PHILOSOPHY OF IFA DIVINATION

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Dedication

This thesis is dedicated to the Egun. I give praise for all of the guidance you have given me in my life and for specifically for helping me to pursue this education. Thank you for all of your sacrifices.

The idea that Western thought might be exotic if viewed from another landscape never presents itself to most Westerners.

- Amiri Baraka (1963)

Chapter One

Introduction to Quantum Mechanics

1.1 Philosophy of Classical Physics

The Encyclopedia Britannic describes science as:

> any system of knowledge that is concerned with the physical world and its phenomena and that entails unbiased observations and systematic experimentation. In general, a science involves a pursuit of knowledge covering general truths or the operations of fundamental laws. (Encyclopaedia Britannica, 2020b)

Someone with an uncritical eye could easily take this abstract definition at face value without feeling the need to elaborate on the concepts of "unbiased observation" and "systematic experimentation". Despite this, these concepts serve integral roles in shaping our understanding of what fits inside and outside of the scope of scientific knowledge. In doing so these concepts help to define an epistemology, or set of methods used to generate knowledge, by which science may progress.

Classical physics structures itself upon an empiricist epistemology in which one acquires knowledge through experience and observation rather than through intuition alone (Jeans, 2008). This means that within this system of knowledge, the validity of any theory depends upon some burden of empirical evidence rather than on some more abstract conception of truth. Further, along with necessitating this empirical evidence, physics also describes a set of philosophies with which this evidence must abide. First, empirical evidence in physics must agree with the philosophy of materialism which conjectures "the independent existence of matter" (Nkrumah, 1970). Within this framework, matter forms the fundamental building blocks of reality with entities such as consciousness existing as emergent properties of critical organizations of this matter (Nkrumah, 1970). Along with materialism, empirical evidence in classical physics must also attend to a deterministic philosophy in which all events owe their existence to a set of causes (Encyclopaedia Britannica, 2020a). Holding fast to this determinism, uncertainty present within empirical evidence must always originate from epistemology of measurement rather than from the ontology, or being, of the underlying reality subjected to this measurement.

Immanuel Kant's contribution to the philosophy of science played an instrumental role in formulating this epistemology used by classical physics. Positioning himself as a rationalist thinker, Kant questioned the fidelity by which our senses can make measurements of the natural world (Jeans, 2008). In his writing, Kant postulated that instead of having access to some fundamental reality through our senses, two sets of concepts shape our understanding of the natural world. These consist of *a priori* concepts - truths innate to all human minds; and *a posteriori* concepts - truths only accessible through experience in the physical world (Jeans, 2008).

Placing the existence of *a priori* and *a posteriori* concepts in relation to empirical evidence, Kant articulated that empirical evidence operates as "judgements of experience" (Kant and Belfort, 1891). Considering that *a priori* concepts help to frame our judgements, Kant's connection between empirical evidence and human judgement suggests that those *a posteriori* truths learned from observation are essentially mappings of the *a priori* concepts held by those performing the judgement. By articulating this importance of *a priori* concepts in the generation of *a posteriori* knowledge, Kant suggests that any knowledge that humans acquire depends heavily upon the frame of reference of those who acquired it.

Considering Kant's interjection, classical physics' *a priori* concepts of materialism and determinism surely shape the range of knowledge accessible by this field. By privileging theories and evidence that uphold these concepts, this field has produced accurate predictions of the natural world which have in turn spurred the development of sophisticated technologies. However, in its disregard for other contradictory *a priori* concepts, it holds the potential to ignore aspects of our reality that fall outside of the scope of knowledge that this field has designated for itself. Considering this, these postulates of materialism and determinism, encapsulated by Kant's assertion that nature consists only of "the sum-total of all objects of experience" (Kant and Belfort, 1891), could limit us from achieving a more complete understanding of the Universe in which we live.

1.2 Introduction to Quantum Mechanics: Wave Functions, Operators, and Uncertainty

Prior to the development of Quantum Mechanics, little reason existed to question the supremacy of determinism and materialism in conceptualizing the physical world. However, Quantum Mechanics quickly reversed this by forcing physicists to reconsider the ontology of particles. Instead of speaking to the point-like particles of classical physics with determined position and momentum, Quantum Mechanics offers an alternate conception describing particles through non-localized and abstracted wave functions.

The wave functions of quantum mechanics exist within an infinite-dimensional space referred to as Hilbert space in which each point in space represents its own dimension. These wave functions serve as infinite-dimensional vectors which help to determine the particle's quantum state describing the characteristics of the system. The Hilbert space representation of wave functions depicts them using Dirac notation as $|\psi(t)\rangle$, however, one can re-express this as a function of position by taking inner product of the wave function and some position vector $|x\rangle$ such that

$$\langle x|\psi\rangle = \psi(x) \tag{1.1}$$

This description of particles and systems immediately stands out from those in classical mechanics through this abstracted and spatially dispersed expression. Particles within this framework no longer get described as point-like particles, instead as functions defined over space. Additionally, while classical physics stipulates that particles can't occupy more than one state at a single time (for example: one particle can't have two different positions/momenta at the same time within the same inertial coordinate system), the Principle of Superposition in Quantum Mechanics allows for wave functions to be composed of the wave functions of several quantum states. This implies that quantum systems can occupy multiple states at the same time such that (Shankar, 1980)

$$|\psi(t)\rangle = \alpha|\psi_1\rangle + \beta|\psi_2\rangle + \gamma|\psi_3\rangle \tag{1.2}$$

In addition to wave functions, Quantum Mechanics also includes another important set of mathematical objects referred to as operators. These operators perform transformations on vectors in Hilbert space such that (Shankar, 1980)

$$\hat{\Omega}|V\rangle = |V'\rangle \tag{1.3}$$

for the operator $\hat{\Omega}$, initial vector $|V\rangle$, and transformed vector $|V'\rangle$. Predicting the resulting transformation caused by the application of an operator to a vector often presents a challenge. However for the specific vectors, referred to as the eigenvectors of an operator, applying the operator to the eigenvector results in simply a scalar transformation. Thus, for an eigenvector $|V\rangle$ with eigenvalue of ω of operator $\hat{\Omega}$, the application of the operator will yield (Shankar, 1980)

$$\hat{\Omega}|V\rangle = \omega|V\rangle \tag{1.4}$$

Of the entire set of operators in Hilbert space, Quantum Mechanics restricts itself to the set of operators with real-valued eigenvectors referred to as Hermitian.

Of those operators in Quantum Mechanics, the Hamiltonian operator features the most prominently throughout this theory. Quantum Mechanics defines the Hamiltonian operator

$\hat{H}$ as the sum of the particle's kinetic energy and some potential, V(x), such that $\hat{H} = \frac{\hbar^2}{2m}\nabla^2 + V(x)$ (Shankar, 1980). This operator serves an important role in the Schrodinger Equation describing the time evolution of wave functions (Shankar, 1980):

$$H|\psi(t)\rangle = i\hbar\frac{d}{dt}|\psi(t)\rangle \tag{1.5}$$

This time evolution drives oscillations of the wave function in the complex plane while having no effect on its position in space. Further, by multiplying by the Unitary Operator $U(t) = e^{-iHt/\hbar}$, time independent wave functions can emulate this evolution in time such that given some wave function at some initial time, $|\psi(0)\rangle$ the wave function at some later time is defined (Shankar, 1980):

$$|\psi(t)\rangle = U(t)|\psi(0)\rangle \tag{1.6}$$

Aside from the Hamiltonian, two other Hermitian operators appear prominently in Quantum Mechanics: the position operator $\hat{X}$ and the momentum operator $\hat{P}$. When applied to eigenvectors in the eigenbasis of the X operator, these operators return the eigenvalues (Shankar, 1980):

$$\langle x|\hat{X}|x'\rangle = x\delta(x - x') \tag{1.7}$$

$$\langle x|\hat{P}|x'\rangle = -i\hbar\delta'(x - x') \tag{1.8}$$

Further, when these operators act upon a wave function (expressed as functions of some coordinate basis x) we get relations (Shankar, 1980):

$$\langle x|\hat{X}|\psi'\rangle = \hat{X}\psi(x) = x\psi(x) \tag{1.9}$$

$$\langle x|\hat{P}|\psi'\rangle = \hat{P}\psi(x) = -i\hbar\frac{d}{dx}\psi(x) \tag{1.10}$$

These definitions of the position and momentum lead us to one of the most consequential results of Quantum Mechanics, the Heisenberg Uncertainty Principle. To do this, we must first define the condition for commuting operators. Given two arbitrary operators $\hat{\Omega}$ and $\hat{\Lambda}$

these operators commute if (Shankar, 1980):

$$[\hat{\Omega}, \hat{\Lambda}]|V\rangle = (\hat{\Omega}\hat{\Lambda} - \hat{\Lambda}\hat{\Omega})|V\rangle = 0 \tag{1.11}$$

When fulfilled, this condition indicates that these exists a set of vectors $|V\rangle$ that are an eigenvector of both operators such that (Shankar, 1980):

$$\hat{\Omega}|V\rangle = \omega|V\rangle \tag{1.12}$$

$$\hat{\Lambda}|V\rangle = \lambda|V\rangle \tag{1.13}$$

Testing this condition of commutation on operators X and P produces:

$$\langle x|[\hat{X}, \hat{P}]|\psi\rangle = \langle x|(\hat{X}\hat{P} - \hat{P}\hat{X})|\psi\rangle \tag{1.14}$$

$$= x(-i\hbar\frac{d}{dx})\psi(x) - (-i\hbar\frac{d}{dx})x\psi(x) \tag{1.15}$$

$$= -i\hbar x\frac{d\psi(x)}{dx} + i\hbar\frac{dx}{dx}\psi(x) + i\hbar\frac{d\psi(x)}{dx}x \tag{1.16}$$

$$= i\hbar\psi(x) \tag{1.17}$$

This result, $[\hat{X}, \hat{P}] = i\hbar$, commonly referred to as the Canonical Commutation Relation, shows that the position and momentum operators do not commute. This implies that no wave functions exist that are eigenvectors of both the position and momentum operators. As a result, an individual wave function cannot have eigenvalues for both of these operators at the same time. Thus no particle in a Quantum Mechanical system can have both a definite position and momentum. Re-expressing our result using a small number of manipulations, this relation gives way to the Heisenberg Uncertainty Principle $\Delta X \Delta P \geq \frac{\hbar}{2}$ quantifying the minimum product of the uncertainties of these two measurements.

This statement of uncertainty further contributes to Quantum Mechanic's deviation from classical physics. Contrary to the determinism of classical mechanics which describes uncertainty as an epistemological artifact, Quantum mechanics stipulates that its most fundamental constituents have uncertainty inherent within them. In this way, the Heisenberg uncertainty principle asserts the ontological significance of uncertainty. This philosophical deviation between classical physics and Quantum Mechanics operates as the first of several disagreements between these theories and helps to question the validity of the basis of *a priori* concepts upon which classical physics stands.

1.3 Measurement

The preceding summary of Quantum Mechanics provided a basis for the mathematics of this theory but does little to interpret the physical significance of wave functions and operators. This difficulty to interpret the mathematics of Quantum Mechanics extends far beyond the discussion in this paper and instead drives much of the evolution of this theory.

Max Born proposed the most famous interpretation of the quantum wave function suggesting that wave functions relate to the probability that the particle occupies a specific state. Born's Rule states that given eigenvectors $|\psi_i\rangle$ with eigenvalues λ_i of some operator $\hat{O}$, the probability that an arbitrary wave function occupies the state $|\psi_i\rangle$ is given by (Friebe et al., 2018):

$$Prob^{\hat{O}}_{|\psi\rangle} = |\langle\psi_i|\psi\rangle|^2 \tag{1.18}$$

Thus, the probability of finding a wave function localized at $\vec{\boldsymbol{x}}$ is described by

$$|\psi(\vec{\boldsymbol{x}}, t)|^2 \tag{1.19}$$

This interpretation's use of probability to describe the wave function serves a useful role in predicting the results of quantum systems. However, the lack of determinism in Born's laws has pushed physicists to define new interpretations of this probability in the hope of retrieving some of the *a priori* concepts held dear by classical physics.

The Ensemble and Copenhagen interpretations compete to describe the role of probability in Quantum Mechanics. The Ensemble interpretation suggests that probabilities in Quantum Mechanics indicate the relative frequency, over a large number of observations, of measuring a particle in a specified Quantum Mechanical state (Friebe et al., 2018). Thus, this interpretation conceives of wave functions occupying a varied set of states and one can only associate a specific state with a specific wave function by performing a measurement. According to this interpretation, measurement bears similarity to picking a marble from a bag containing blue, red, and yellow marbles; once can only give the probability of picking a marble of a specific color even though the color of each individual marble is never undetermined. Here, Born's Law suggests an that Quantum Mechanics contains epistemological uncertainty originating from our inability to understand the entire system but not from the system itself.

The Copenhagen interpretation offers an alternative to the Ensemble interpretation in addressing question of probability in Quantum Mechanics and many physicists today adhere to this interpretation. The Copenhagen Interpretation posits Quantum Probabilities as ontological descriptions of quantum phenomena and as such allows for the existence of particles occupying a superposition of quantum states. These superpositions only describe unmeasured particles and when measured (equivalent mathematically to applying an operator to a wave function) the particle "collapses" into one of the states composing this superposition (Friebe et al., 2018). Here, the Quantum Probabilities represent the probability that any one particle will collapse into a given Quantum State. While there exists a nonzero probability that an unmeasured particle will collapse into any of it's component state, the process of collapse requires the particle to essentially pick one state. Thus the process of measurement and collapse under the Copenhagen interpretation sets to zero the probability that the particle occupies any state other than the one measured.

1.4 The Measurement Problem

Both of these interpretations of the physical implications of Quantum Mechanics present unique problems. While affirming the role of determinism in Quantum Mechanics, the Ensemble Interpretation struggles by describing the phenomena of large numbers of Quantum Systems rather than of individual systems (Friebe et al., 2018). Considering that physicists want their theories to predict the actions of individual systems, this problem in the Ensemble interpretation dissuades scientists from adopting it as a description of Quantum Mechanics. Instead, the Copenhagen Interpretation's application to individual systems appears as a more robust interpretation of the underlying physics. Further, in its interpretation that particles occupy in a probabilistic superposition of multiple states prior to measurement, this interpretation appears to uphold the importance of uncertainty within Quantum Mechanics as suggested by the Heisenberg Uncertainty Principle. Despite this alignment, the Copenhagen Interpretation presents a challenge, know as the Measurement problem, in its conception of the collapse of wave functions.

In the Copenhagen interpretation, the collapse of wave functions from a superimposed state to a single state occurs instantaneously and serves as a discontinuous change in quantum states. This causes concern because many of the main theories in physics relies upon an understanding that nature abhors discontinuous changes. Further, considering that the Schrodinger equation describes time-evolution of wave functions in a continuous manner, physicists doubt that Quantum Mechanics relies upon both continuous and discontinuous phenomena to generate change (Bohm, 1993). The debate over the significance of wave function collapse hearkens back to the infancy of Quantum Mechanics. According to Neils Bohr the mathematics of Quantum Mechanics serve as an abstraction of an underlying physical reality. Within this mindset, Bohr viewed the collapse of the wave function as a concept lacking in physical meaning and standing in place of a process beyond our epistemological ability to comprehend (Bohm, 1993). Alternatively, Heisenberg argued that the collapse has a true physical significance and represents the physical process by which wave functions evolve when measured (Friebe et al., 2018). In this way, Heisenberg's conception of collapse posits it as an ontological reality of quantum systems.

Beyond the physical implications of the collapse, more complications arise in the Quantum

Measurement Problem from the interaction between quantum systems and macro-systems. Considering that the process of measurement collapses the wave function of quantum systems, the logical consequence of this suggests that the ability of a quantum system to occupy any one quantum state depends ontologically upon some macro-system measuring it (Friebe et al., 2018). However, since these same quantum systems form the basis from which macro-systems compose themselves, this would imply that macro-systems also depend ontologically on some other system measuring them. Using this "Schrodinger's cat" paradox as a point of departure, Bohr suggested that neither quantum systems nor macroscopic systems exist on their own and instead constitute an "un-analyzable whole". (Bohm, 1993) This addition moves us even further from the determinism of Quantum Mechanics and suggests that macro-systems, in addition to quantum systems, can exist in states of superposition. This promotes uncertainty from an simply an aspect of the quantum world to instead a concept playing an important role in affecting the macro-systems that classical physics attempts to describe.

Lastly, the famous Einstein-Podolsky-Rosen (EPR) paper introduces one final complication involved in the Measurement Problem. Here, in the hopes of proving the incompleteness of Quantum Mechanics, the authors discuss in detail the example of a quantum system composed of two particles. In this example, the quantum state has a known value for some observable while leaving the states of the individual particles undefined. The authors point out that upon measuring the state of one of these particles, the other particle's wave function must also collapse in order to preserve the overall state of the quantum system (Einstein, Podolsky, and Rosen, 1935). For example, given particles A and B which compose a quantum system with no net spin, if one measures the spin of particle B in the z direction as $\frac{-1}{2}$, particle A must have a spin in the z direction of $\frac{1}{2}$ for the system as a whole to have no net spin. Thus, while neither particle initially had a definite spin, measuring one particle's spin immediately determined the spin of both. This thought experiment uncovers non-locality within Quantum Measurement showing that factors spatially separated from a particle can still have effects on it. Considering that Special Relativity mandates that information cannot travel faster than the speed of light, this instantaneous connection between "entangled" particles generates even more conflict between Quantum Mechanics and the rest of physics. In the mind of Einstein and the other authors of the EPR paper, this violation of Special Relativity proved the incompleteness of Quantum Mechanics.

1.5 Summary

The developers of classical physics structured this field upon a foundation of three *a priori* concepts: materialism, determinism, and empirical evidence. Building from this foundation, classical mechanics made great predictions for the physics of the human, celestial, and electromagnetic world. However, this field took little time to question whether its *a priori* concepts actually formed a complete description of reality. Quantum Mechanics highlighted this lack of critical examination by investigating the ontology of the smallest particles in our Universe and in doing so, uncovered a reality drastically different from that of classical physics. Rather than ruled by determinism and materialism, Quantum Mechanics portrayed reality as governed by uncertainty and filled with seemingly un-physical phenomena. While Quantum Mechanics contains uncertainty in measurement, systems existing in states of superposition, and non-locally entangled particles, it still does well at predicting the behavior of microscopic systems. Considering this, one must ask whether there exists a set of *a priori* concepts, alternate to those of classical physics, which agree with (or qualify) the results of Quantum Mechanics and form a better description of the true nature of our reality.

Chapter Two

Yoruba Philosophy

The discussion in chapter 1 highlights Quantum Mechanics' conflicts with the *a priori* concepts of Classical Physics and its subsequent inability to explain phenomena such as uncertainty and measurement. Considering this clash, approaching these topics in Quantum Mechanics from a perspective privileging a different set of *a priori* concepts may provide new insights. This paper will use the philosophy of Ifa Divination, from the Yoruba people of Southwestern Nigeria, to provide a set of concepts alternate to the West's *a priori* concepts of determinism, materialism, and empiricism. After exploring these concepts in this chapter, and investigating the hidden variable theory solutions to the Measurement Problem in chapter 3, these concepts will help inform an "Ifa interpretation" of Quantum Mechanics discussed in chapter 4.

2.1 Introduction to Ifa Philosophy

Within a Western frame of reference, Ifa's focus on the spiritual aspects of human life and society make it appear as simply a traditional religion. However, in reality Ifa embodies much of Yoruba culture encasing the traditional Yoruba's spirituality, philosophy, science, medicine, art, and music. The integration of this wide variety of topics within Ifa results from the traditional Yoruba conception of the world as one fundamentally imbued with spirit.

Philosopher Chiedozie Okoro terms this concept as "integrative metaphysics" in which both life-force and material serve as the fundamental constituents of reality (Okoro, 2017). While these building blocks of nature exist independent of one another, life-force takes precedence in such way that all material is imbued with this spirit (Okoro, 2017). Built upon these *a priori* concepts of integrative metaphysics and the spiritual primacy of nature, traditional Yoruba thought acknowledges few partitions between the physical and the spiritual aspects of reality. As a consequence, Ifa serves to codify both the physical and spiritual facets of traditional Yoruba life.

Ifa expounds its knowledge within the Odu Ifa, its literary corpus maintained by oral transmission between generations Babalawos (traditional priests). Divided into 256 sections referred to as Odu, this corpus utilizes short poems referred to as the ese Ifa to speak to a wide variety of topics pertaining to traditional Yoruba society (Abimbola, 1977). Often presenting short allegorical stories, the ese provide examples of situations, experiences, and problems that could afflict practitioners of Ifa along with the solutions most in alignment with Yoruba belief. The Orisha, the Yoruba divinities reigning over particular aspects of the physical world, appear frequently within the ese as characters whose actions serve as both models and warnings for humans. Examples of the Orisha include: Olodumare, the Supreme God; Yemoja, the deity of the Ocean, motherhood, and children; Aje, the deity of wealth and cowries; and Shango, the deity of lightning and thunder.

2.2 Ori: Destiny

In this discussion of Ifa, three of its beliefs serve important roles in defining a Yoruba conceptions of time and physical reality. The first of these is Ori. Traditional Yoruba thought argues that throughout their lives, all humans bear an Ori, an inner head picked in heaven (orun) prior to birth (Abimbola, 1976). The Ori serves mOny roles to its owner by helping to determine their personality, skills, and personal flaws. However, chief among these roles, the Ori dictates its owner's destiny. Thus, to the traditional Yoruba, the choice of an Ori effectively serves as the choice of one's destiny predetermining their success or failure in life (Abimbola, 1976). After one chooses their Ori and enters the physical world, the destiny associated with their Ori remains fixed such that no amount of prayer or sacrifices can alter it (Gbadegesin, 2004). Further, this conception of destiny depicts it as a potential for success such that a good Ori guarantees success only when paired with the hard work of its owner (Abimbola, 1976). While Ori plays such an important role in informing the destinies of those people who hold it, the exact contents of one's Ori remain outside of the realm of human knowledge. Therefore, to learn the specific attributes of their Ori, one must supplicate Orunmila, the Orisha of divination, present when people choose their Ori in heaven prior to birth (Abimbola, 1976).

The Ifa interpretation of Ori and destiny presents an interesting conception of success and failure. Here, destiny helps to define the space of all possible outcomes rather than simply predetermining one specific outcome. Ori predetermines how much one has the capacity to achieve in life and yet only experience will show their final achievements. Therefore, someone with a poor Ori who exerts a lot of effort in their lifetime could achieve as much or more than someone who has a great Ori but works towards the wrong goals with little effort. In this way, Ori presents a malleable conception of destiny which incorporates human action in the determination of a final result. Extrapolating from this to define a Yoruba outlook towards the conception of "future", the concept of Ori suggests that the future depends upon human initiative within a range of possible realities as determined by the will of the spiritual world.

2.3 Egun: Ancestors

Looking at the concept of Ori helps to define the frame through which the traditional Yoruba view the future, similarly, looking towards the idea of Egun helps to describe their conception of the past. The Egun embody the the Orisha of the ancestors whose depictions in the

Egungun masquerade is portrayed in Figure 1. Within the perspective of Ifa Philosophy, the Egun serve as a spiritual force providing support and guidance for humans (Temple, 2019). As such, Ifa practitioners frequently venerate the Egun for their role as a source of vital stability, guidance, and protection. While the Egun represents those who have passed away, the traditional Yoruba still considers these people as integral participants in their communities. Dr. Ifeanyi Menkiti describes this as an aspect of the Yoruba conception of personhood marked by a "movement from an it to an it" (Menkiti, 2004). Within this perspective, the traditional Yoruba derive their humanity or personhood from their incorporation into their community. Thus, one gains this personhood during their youth and only loses it once they have died and been forgotten (Menkiti, 2004). Through the incorporation of long gone ancestors into community life, the Yoruba conception of community posits that these ancestors still have their role to play in community life.

These conceptions of Egun and ancestors help to define the traditional Yoruba interpretation of "past". Seeing that ancestors can effect the lives of those in their community, the Yoruba understand the importance that the past has in determining the future. However, this interpretation extends further to suggest that the past actively participates in determining the present and the future. Considering this role of ancestors suggests that the traditional Yoruba blur the lines between past, present, and future by implying that these times exist with an inherently co-dependant nature.

2.4 Divination: Measurement

Lastly, the process of Ifa divination plays a central role in defining traditional Yoruba philosophy. The Odu Ifa describes the origins of this practice as beginning with Orunmila, the Orisha of divination, who worked as a very successful diviner and healer during his life. Despite this success on Earth, Orunmila returned to Orun (heaven) after getting into an argument with one of his sons. During this time away, the Earth fell into dismay as women were infertile, all rain ceased, and the ground yielded no food. At the request of many suffering people, Orunmila's sons visited him in Orun begging for him to return to Earth and use his divination to bring back peace and tranquility. He denied this request and instead provided his sons with 16 palm nuts through which to perform divination and access his supernatural wisdom and insight (Abimbola, 1977). From the precedent set by this story, Ifa practitioners now use divination to commune with Orunmila in order to seek guidance before difficult decisions, to find solutions to their problems, and to learn more about their destiny and Ori (Taiwo, 2004).

Babalawos practice divination in response to questions posed by their clients. This process begins when a client comes to the Babalawo's home and symbolically whispers their question or problem to Ifa (Orunmila) (Taiwo, 2004). After this, the Babalawo uses his opele (divining chain; more popular than using 16 palm nuts) consisting of 8 half-nuts with concave and convex sides attached one after the other on a piece of chain (or leather) (Abimbola, 1976) as shown in Figure 2. The Babalawo casts the chain in front of him and matches the pattern exhibited by the chain (whether they are concave or convex side up and in which order) to the corresponding sign of one of the 256 Odu. Each Odu has a particular connotation which the Babalawo can refer to in addressing the client's problem (Abimbola, 1976). Further, the Babalawo also takes time to recites this Odu for the client who then listens for situations or solutions within this Odu that address his or her problem (Taiwo, 2004).

This process of divination allows Babalawos to peel back the curtains of reality revealing the spiritual forces underpinning their client's lives. By acquiring this knowledge, their clients have the option to redirect their actions to stand in alignment with these forces. Built upon the conception that a spiritual life-force pervades all reality, Ifa asserts that specific orientations of this life-force will predictably lead to specific situations in the physical world. Under this assumption, divination operates as a process of investigation mapping spiritual forces to physical events and situations (Okoro, 2017). While divination ascertains the effects caused by the spiritual forces operating at any one moment, it remains unable to definitely state what these forces are and by what methods they create these effects. Instead, the Odu abstracts a much more complicated set of spiritual forces by choosing to only describe their effects (Okoro, 2017). In this way, divination serves as a process for prediction and measurement but doesn't make any ontological assessment of the forces it measures.

2.5 Summary

The world-sense presented in the philosophy of Ifa Divination contains both epistemological and ontological differences from that suggested by the world-view of Western Physics. The traditional Yoruba perceived reality as fundamentally both physical and spiritual with a life-force pervading all things. Governed by the Orisha and the late Egun, this reality privileged spiritual forces as those most important in defining the world in which we live. Further, traditional Yoruba thought stipulated that beyond operating in dialectic with the work of human initiative, these forces also constrain and predestine the limits of all possible situations. Despite the importance of these spiritual forces in the lives of Ifa practitioners, only the process of divination can identify the specific alignment of forces generating the effects one experiences in their life.

Chapter Three

Hidden Variables a Solution to the Quantum Measurement Problem

3.1 Hidden Variable Theories

Ifa philosophy describes a reality governed by the sometimes unpredictable whims of the spiritual world. Here, these spiritual forces holding the reigns of reality lie outside of the realm of human conception. Returning to Quantum Mechanics, the Hidden Variable interpretation bears striking resemblance to Ifa's conception of the world by describing the uncertainty of Quantum Mechanics as the consequence of a deterministic theory lying outside of our understanding.

Hidden variable theory grew out of debates about the ontological completeness of Quantum Mechanics. As mentioned in Section 1.4, Einstein showed in his famous EPR paper that Quantum Mechanics allowed for strange non-local phenomena through quantum entanglement. By pointing out the conflict between entanglement and Special Relativity, Einstein attempted to prove Quantum Mechanics' incompleteness and attributed this non-local phenomena simply to the epistemological framework utilized by this theory. In search for some ontological truth deeper than those uncovered in Quantum Theory, and holding fast to Einstein's famous quote "God does not play dice with the Universe" (Smolin, 2019), Hidden

Variable Theories seek to uncover an underlying mathematics, defined by some "hidden variables", which when included can explain the uncertainty we see in Quantum Mechanics by some deterministic means.

3.2 Bell's Inequalities

John Stewart Bell's 1964 paper, *On the Einstein Podolsky Rosen Paradox*, contributed significantly to our understanding of hidden variable theories through its formulation of a set of important inequalities. In this paper, Bell re-examines the situation from the EPR paper of two spin one-half particles incorporated into a known singlet state (Bell, 1964). He defines the spin components of these particles as σ_1 and σ_2 along with unit vectors $\vec{a}$ and $\vec{b}$ defining axes to measure the directions of these spins. Further, the singlet state of these particles has no net spin so when $\vec{a}$ and $\vec{b}$ point in the same direction, the measurements yields opposite results (+1 and -1) (Bell, 1964). Bell incorporates hidden variables by assuming the existence of a set of parameters, λ, belonging to each particle such that these parameters and the unit vector defining the direction of measurement for spin entirely determine the resultant measurements of A or B ($\sigma_1 \cdot \vec{u}$ or $\sigma_2 \cdot \vec{u}$ for some unit vector $\vec{u}$) (Bell, 1964). Further, in this assertion, Bell assumes locality by suggesting that the result of measurements A ($\sigma_1 \cdot \vec{a}$) and B ($\sigma_2 \cdot \vec{b}$) do not depend on each other (Bohm, 1993). By defining these parameters λ, Bell essentially removes the role of uncertainty from Quantum Mechanics instead posing it as a deterministic process.

Next, Bell derives an equation for the expected value generated by multiplying the measurement $\sigma_1 \cdot \vec{a}$ by $\sigma_2 \cdot \vec{b}$ (Bell, 1964):

$$P(\vec{a}, \vec{b}) = \int d\lambda \rho(\lambda) A(\vec{a}, \lambda) B(\vec{b}, \lambda) \tag{3.1}$$

for some probability distribution of λ normalized to unity (Bell, 1964). Considering the situation in which $\vec{a} = \vec{b}$, the net zero spin of the quantum system indicates that measurements A and B must yield opposite results such that $A(\vec{a},\lambda) = -B(\vec{a},\lambda)$. Introducing this information into equation 3.1, Bell re-expresses this equation as (Bell, 1964):

$$P(\vec{a},\vec{b}) = -\int d\lambda \rho(\lambda) A(\vec{a},\lambda) B(\vec{a},\lambda) \tag{3.2}$$

Then, using equation 3.2 and considering another unit vector in which to measure spin, $\vec{c}$, Bell calculates the difference $P(\vec{a},\vec{b}) - P(\vec{a},\vec{c})$ in order to generate the inequality (Bell, 1964):

$$1 + P(\vec{b},\vec{c}) \geq |P(\vec{a},\vec{(b)}) - P(\vec{a},\vec{(c)})| \tag{3.3}$$

Using an approximation for small $|\vec{b} - \vec{c}|$ equation 3.3 further reduces to (Bell, 1964):

$$1 + P(\vec{b},\vec{c}) \geq |\vec{b} - \vec{c}\,| \tag{3.4}$$

Introducing the expectation value of $P(\vec{b},\vec{c})$ expected by Quantum Mechanics (Bohm, 1993):

$$P(\vec{b},\vec{c}) = -\vec{b} \cdot \vec{c} \tag{3.5}$$

and including this into equation 3.4, Bell indicates that for specific choices of unit vectors $\vec{b}$ and $\vec{c}$ this inequality does not hold.

Both this theoretical investigation, along with Quantum Mechanical experiments, have indicated that the inequality in equation 3.4 does not hold for all choices of $\vec{b}$ and $\vec{c}$. As a consequence, the local hidden variable theory used to formulate these inequalities cannot adequately describe Quantum Mechanics (Bohm, 1993). Rather, the measurements performed on independent particles must allow form some non-local dependence upon the state or measurement of the other. Through expounding this, Bell's inequalities stipulate that any hidden variable theory must allow for non-local phenomena.

3.3 De Broglie-Bohm Theory

Working from the conclusions drawn by Bell's Inequalities, the de Broglie-Bohm theory adopts non-locality in its hidden variable interpretation of Quantum Mechanics.

This theory structures itself upon three main postulates. First, this theory, like the Copenhagen interpretation, argues that the Schrodinger equation (equation 1.5) governs the time evolution of the wave function (Friebe et al., 2018).

Next, the de Broglie-Bohm theory introduces hidden variables by suggesting that all quantum particles have a determined position in space denoted by Q(t) and that all quantum systems have a phase, S (Friebe et al., 2018). The inclusion of these hidden variables for position, Q(t), initially seem to violate the uncertainty in particle positions described by Born's Law. However, this theory addresses this by including the "Quantum Equilibrium Hypothesis" stating that $|\psi|^2$ represents the probability of finding a particle to have a specific initial position (Friebe et al., 2018). This recasts measurement not as a process collapsing the wave function but rather as one which identifies that particle's position which had never existed in superposition. Hence, the uncertainty in Quantum Mechanics speaks to an epistemological limit in our knowledge of the initial conditions of all particles rather than a ontological reality of these particles themselves.

The Guidance Equation completes the de Broglie-Bohm theory by describing the time evolution of the position of Bohmian particles as a function of the phase, S, of the entire quantum system (Friebe et al., 2018):

$$\frac{dQ_i}{dt} = \frac{\nabla_i S}{m_i} \tag{3.6}$$

with m_i the mass of the ith particle. This description of the time evolution of particles suggests that these particles evolve in time completely deterministically given an value of Q at some initial time.

While this theory succeeds in describing Quantum Mechanics deterministically in a no-collapse regime, it still abides by the important results of Quantum Mechanics described earlier. First, it holds true to the Heisenberg Uncertainty principle by declaring both the position variables and the phase as hidden. Considering that these variables lie beyond our bounds to measure, there exists no way to measure quantum particles such as to know

Q(t) as a function of time even though these hidden variables evolve deterministically. This agrees with the result of the Uncertainty Principle barring us from knowing a both a particles position and momentum. Further, this theory agrees with the result of Bell's inequalities that all hidden variable theories must allow for non-locality. By defining the time evolution of the position variables as dependant upon the phases of the entire quantum system, this evolution occurs non-locally.

3.4 Summary

Hidden variable theories of Quantum Mechanics hold the potential to describe the uncertainty of Quantum Mechanics as simply an epistemological artifact of some deeper mathematical truth. The formulation of Bell's Inequalities show that these hidden variable theories must allow for non-local phenomena in order to agree with the entanglement observed in Quantum theory. The de Broglie-Bohm theory arises as a non-local hidden variable theory which defines hidden variables of position, belonging to each quantum particle, and phase, belonging to the entire quantum system. Through maintaining that quantum particles have positions which evolve in relation to the phase of the quantum system, this theory recasts the uncertainty of Quantum Mechanics as simply an uncertainty in our knowledge of initial conditions.

Chapter Four

Quatum Measurement Through the Lens of Yoruba Philosophy

4.1 Towards a Ifa interpretation of Quantum Mechanics

The de Broglie-Bohm interpretation resolves issues of the measurement problem in a way consistent with classical physics's *a priori* concepts of determinism and materialism. Despite this success, turning towards the Yoruba Ifa Philosophy offers a unique opportunity to use fundamental concepts of this philosophy to inform new solutions to the measurement problem.

Comparing the conceptions of matter held by Quantum Mechanics to those of Ifa offers a good point of departure. Starting with Quantum Mechanics, this theory does little to challenge classical physics' *a priori* conception of materialism stating that all things fundamentally owe their composition to matter. However, Quantum Mechanics does stand up to the concept of determinism by using Born's Law and the Heisenberg Uncertainty Principle to highlight the importance of uncertainty in nature. Alternatively, Ifa philosophy does the opposite of Quantum Mechanics by challenging materialism and supporting determinism. At its heart, Ifa Philosophy refutes materialism by asserting that all material is imbued with spirit and as such, both matter and spirit constitute the fundamental building blocks of reality. Further, Ifa supports determinism by doing little to speak to the possibility that uncertainty exists within everyday measurement. Considering these points of departure, the de Broglie-Bohm interpretation's maintenance of determinism in Quantum Mechanics positions it as a good choice from which to model an Ifa interpretation of Quantum Mechanics.

Utilizing the de Broglie-Bohm interpretation's conception of hidden variables, an Ifa interpretation of Quantum Mechanics could similarly introduce as hidden variables unique to each quantum system. These could include a set of position coordinates belonging to each particle and a phase unique to the entire wave function. The inclusion of these two hidden variable help to describe a deterministic time evolution of particle's positions similar to in the de Broglie-Bohm interpretation. However, in order to maintain the concept of integrative metaphysics fundamental to Ifa, an Ifa interpretation must expand upon the hidden nature of these variables. Here, the theory could posit that these variables have a hidden nature because they originate from the spiritual or conscious components dual to the material particle. Therefore, these particles can have deterministic realities entirely dependent upon this concept of integrative metaphysics.

While Ifa presents a deterministic conception of reality, looking to only the physical components of this reality for causes of events suggests that uncertainty plays an important role in determining the future. In the discussion of Ori and destiny, Ifa philosophy identifies a whole host of forces affecting the outcome of one's future. This includes the content of one's Ori, the amount of hard work they put in, and the supernatural forces acting to either help or hinder their progress. Thus, taking into consideration these non-physical driver of change, in addition to the physical ones, reduces the role of uncertainty such that all actions have a definite set of physical and spiritual causes. Using this understanding, any discussion of the time evolution of quantum systems must include both physical and spiritual phenomena.

To start, the Ifa interpretation can follow the lead of the de Broglie-Bohm interpretation and borrow the use of the Schrodinger equation to describe the time evolution of wave functions. Seeing that the Schrodinger equation plays an important role in defining the wave function, it makes sense to retain this aspect integral to Quantum Mechanics. Further, to describe the evolution of the hidden position variables, Q(t), this interpretation can modify the guiding equation from the de Broglie-Bohm interpretation. Considering that in the Ifa interpretation, the hidden variables describe the spiritual or conscious aspects of quantum particles, the guiding equation must account for the effects of spiritual forces such as Orisha, Egun, and Ori. This theory can account for these forces by adding one final hidden variable, $E_{spiritual}$ describing the spiritual or conscious effects applied to these particles. The resultant guiding equation then encapsulates all of the phenomena driving the time evolution of Q(t):

$$\frac{dQ_i}{dt} = \frac{\nabla_i S}{m_i} + E_{spiritual} \tag{4.1}$$

This guiding equation follows the result of Bell's inequalities and allows for non-local phenomena in two manners. First, the phase of the wave function describes the quantum system as a whole, instead of individual particle, yet it still has a direct effect on the time evolution of the positions of individual particles. Further, the spiritual or conscious forces at play in the term, $E_{spiritual}$, lie outside of the physical reality of these quantum systems and as such their effects are intrinsically non-local.

The use of hidden variables, the Schrodinger equation, and this new guiding equation allow the Ifa interpretation's perspective of integrative metaphysics to describe Quantum Mechanics as ontologically deterministic. However, in order to agree with the findings of Quantum Mechanics, it must exhibit the uncertainty found within Quantum Mechanics. In order to recover this lack of determinism from Quantum Mechanics, this interpretation casts uncertainty as a product of our epistemological choice to only investigate the world through physical means.

Looking first to the hidden position variables, Q(t), we can imagine these as aspects of the spiritual or conscious components of particles whose projection onto the physics component determines the position of particles. Therefore, anyone measuring these particles physically would only grasp the projection of these variables. It makes sense then that similar to the de

Broglie-Bohm's Quantum Equilibrium Hypothesis, when measured these projections could have distributions agreeing with Born's Law.

Next, the guiding equation explains the time evolution of particles in a purely deterministic manner but remains ineffective when paired with a materialist philosophy. Similar to the position variables, the phase variable defined in the Ifa interpretation also exists as a spiritual projection onto particle's physical reality and as such sits beyond the epistemological reach of physical measurement. Without this knowledge of the phase, the $\frac{\nabla_i S}{m_i}$ term in the guiding equation remains undefined. Further, the term $E_{spiritual}$ describing the effects of the spiritual or conscious forces in the Yoruba pantheon appears only when privileging the equi-primordial nature of spirit and matter. Since any physical investigation will ignore this term, both parts of the right side of the guiding equation remain undefined.

Since physical investigation remains unable to correctly identify any hidden variables or to fulfill the guiding equation, the Ifa interpretation exhibits the uncertainty found in Born's equation and the Heisenberg Uncertainty principle. Ultimately, the determinism in this interpretation results from thorough spiritual or conscious measurement accompanying the usual physical measurement. Ifa philosophy doesn't provide much information from which to model spiritual investigation into the hidden position and phase variables, however the divination process serves as an excellent blueprint from which to describe measurement of the spiritual forces acting upon particles $E_{spiritual}$.

To the Yoruba, the process of Ifa divination recognizes patterns in the alignments of spiritual forces such as the Orisha, Egun, and Ori. From these patterns, this philosophy states that a set of effects logically progresses as described by the 256 discrete situation in the Odu Ifa. Applying this to the term for spiritual forces from the guiding equation, a similar form of divination could identify these spiritual effects. By identifying the specific spiritual situation helping to drive the time evolution of the particle, an analysis of this alignment would then describe its resultant effect $E_{spiritual}$. Therefore, this process of divination would serve as a systematic investigation into the action of these spiritual forces ultimately allowing for this interpretation to deterministically explain the quantum world.

4.2 Conclusion

Constructing an Ifa interpretation of Quantum Mechanics shows that the concepts fundamental to Ifa hold consistent with some of the main experimental findings of Quantum Mechanics. By associating a set of hidden variables with the spiritual or conscious aspect of quantum systems, this interpretation details a non-local and deterministic approach to Quantum Mechanics. Despite this determinism, this interpretation still yields the uncertainty found in Quantum Mechanics when systems are only considered for their physical nature without also investigating their spiritual or conscious aspects.

Considering the myriad questions left unanswered by modern physics (including the measurement problem), the success of the Ifa interpretation stresses the importance of opening one's self to solutions not conventionally considered by Western science. Further, the Ifa interpretation's success shows the innate fallacy present in Western society's understanding of African traditional religions, such as Ifa, as antithetical to logic.

Moving forward, science's thirst for knowledge must take time to consider the unique solutions presented by forms of systematized knowledge such as Ifa. Without doing so, these fields hold the potential to constrain their understandings of the world by holding tight to the hegemonic set Western *a priori* concepts. Instead, by challenging Western science's *a priori* concepts and approaching reality through a holistic lens privileging multiple ways of knowing, science can move past simply making predictions about the natural world and instead explore the underlying truths guiding our reality.

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APPENDIX

Appendix A

Figure A.1 People dressed in masquerade for a Egungun festival in Benin. These masquerades dance in veneration of the Egun (ancestors).

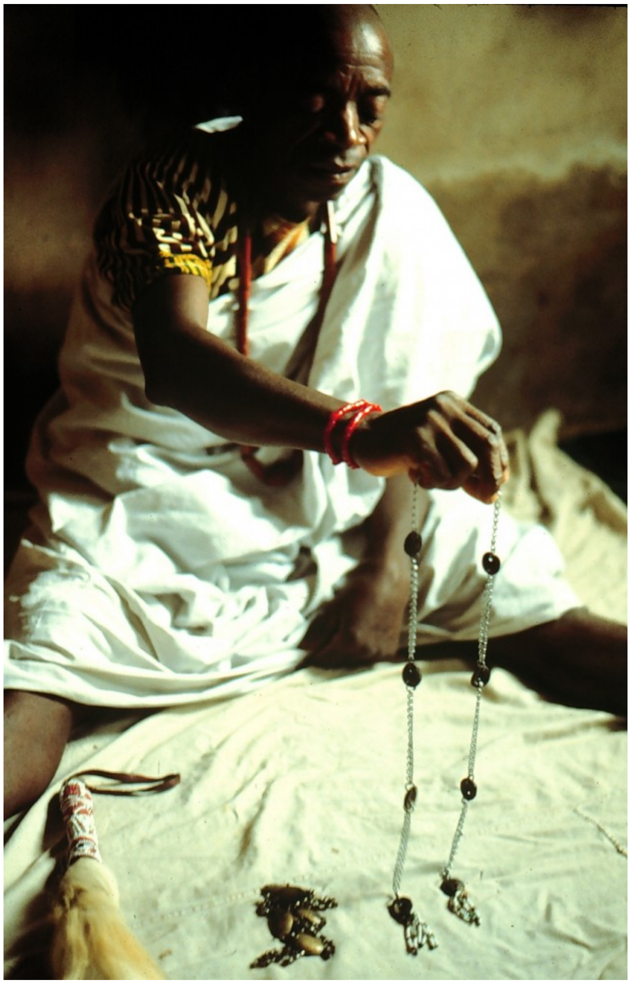

Figure A.2 A Babalawo (traditional priest) casts his Opele (divining chain) in order to perform Ifa divination for a client.