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Causally Active Metaphysical Realism

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Abstract: We postulate that Measurement in Quantum Mechanics forms the basis of a Causally Active Metaphysical Realism. It is Quantum Measurements that give rise to the instantiation of Universals as Properties, processes we refer to as Hylomorphic Functions. The process of measurement is the creation of a quantum of information - a Fact. How this happens is explained differently in different interpretations of Quantum Mechanics, but the creation of a fact is the same in all of them. This combines substance metaphysics and process metaphysics by identifying the hylomorphic functions as causally active processes complementary to physical substances, forming a dualism of both substance and information which mutually interact. We look at this hypothesis in relation to various different interpretations of Quantum Mechanics starting with the Copenhagen Interpretation. Measurements of fundamental properties of matter are the Atomic Universals of metaphysics, which combine to form the whole taxonomy of Universals, including causally inactive Inferences made of separate Atomic Facts. Since the Hylomorphic Functions are causally active, it is possible to suggest experimental tests that can verify this viewpoint.

Keywords: Measurement problem; metaphysics; universals; process metaphysics

1. Introduction

In contemporary research on the relationship between Quantum Mechanics and Metaphysics, the analysis of ontology mostly focuses on objects that have a physical reality.

As an example, Allori [4] describes which components of Quantum Mechanics form a primitive ontology but excludes abstract objects from consideration:

> Why the qualification "primitive ontology," instead of just "ontology" simpliciter? First, the idea is that the primitive ontology does not exhaust all the ontology — it just accounts for physical objects. Other things might exist (numbers, mathematical objects, abstract entities, laws of nature, and so on), and some of them (like natural laws) might be described by other objects in the ontology of a fundamental physical theory.

It is fair to ask if abstract objects can be considered to be part of a primitive ontology also. If the distinction is to be made between physical objects and abstract entities, the question arises: where are abstract objects found in reality, if at all, and how do they interact with the physical objects? This is the Problem of Universals.

People who believe that Universals actually exist are called *Metaphysical Realists*. The two classical versions of Realism are Platonism and the more moderate Realism of Aristotle. Modern Platonism does not have all of the characteristics of classical Platonism, but it does postulate a separate realm of existence for the Universals. This viewpoint was expressed by Frege, especially in his book "The Foundations of Arithmetic" [28]. Other famous mathematicians such as Kurt Gödel have expressed a Mathematical Platonism [53]. Carmichael [14] advocates a type of Platonism he calls "Deep Platonism".

Aristotle gave an alternative to Platonism. In his *Metaphysics* [5], he analyzed the Doctrine of the Forms, and concurred with Plato in the belief that the Forms are real: they provide a conceptual framework that we use to understand the objects of reality, and these concepts exist in their own right. But he had criticisms of the doctrine as Plato described it. The idea that the Forms exist in a separate plane of existence leads to questions about how the world of Forms and the world of reality interact. He argues this way:

> The 'animal', then, present in each species of animals will be animal-itself. Further, from what is this 'animal' in each species derived, and how will it be derived from animal-itself? Or how can this 'animal', whose essence is simply animality, exist apart from animal-itself?

So Aristotle has an ontology different from that of Plato and later Frege. Although he acknowledges the existence of Universals — the Forms — they do not have a separate existence in an ideal world.

The idea that the Forms do not exist apart from things has been termed "Hylomorphism", from the concept hyle — wood or matter — and the concept morphe — form or spirit. This terminology arose out of the Nineteenth Century's appreciation of St. Thomas Aquinas' analysis of Aristotle's thought as it applied to Christian philosophy [51]. Aristotle's viewpoint has been termed a "Moderate" or "Immanent" Realism [9], Although a case can be made for either approach, the main thesis of this paper — that Universals exist as the result of causally active physical processes — advocates a *Causally Active Metaphysical Realism*. It makes the abstract objects of metaphysics as much a part of physics as atoms or electromagnetism. We shall make the case that Universals form with physical objects a duality in physics — that of substance and process ontology. This also means that the instantiation of Universals – Facts – exist independent of and prior to minds.

In the Twentieth Century we have seen the development of Process Metaphysics especially the work of Whitehead [69]. Seibt [59] and Rescher [54], among others, have different versions of Process Metaphysics. In contrast to Substance Metaphysics, Process Metaphysics has processes as the foundation of its ontology, rather than objects. The type of Process Metaphysics discussed here is the more generic type as described by Rescher.

Process Metaphysics is often discussed as an alternative to Substance Metaphysics, but it is certainly possible to combine the two. But, as Rescher notes: "The mixed – and thereby more complicated – option of a theory of things-in-process has not found much favor since the hey-day of Aristotelianism."[1] In this paper, abstract objects will be considered as contingent upon the more fundamental process of instantiation of a property of an object. The process of instantiation is considered part of the basic ontology — it creates information. This establishes the viewpoint that the world consists of both substance and information.

Normally ideas are not considered to affect reality: universals are considered to supervene on the substance of physics. Thus, they are causally inert. Instead, we make the claim that they affect physical substance in and of themselves. The instantiation of a Universal can cause changes in physical substance and alternatively, physical changes can cause the instantiation of Universals.

In claiming that there exist Universals that are causally active, it is incumbent upon us to discuss what experimental tests can be applied to prove that this is actually true. We shall begin by discussing the definition of Universals in Quantum Mechanics, the philosophical implications of their existence, and then the physical implications of their existence, in a testable fashion.

2. Universals, Properties and Particulars

First, we need to define what a Universal is.

E.J. Lowe describes Objects and Universals, as follows [48]:

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[1] Ellis [25] considers a combination of substance and process metaphysics, in the context of scientific essentialism, but a process is limited to be a sequence of physical events, which are defined as some change of energy distribution in the universe.

> Objects are entities which possess, or 'bear', properties, whereas properties are entities that are possessed, or 'borne' by objects. Matters are complicated by the fact that properties can themselves possess properties, that is, so–called 'higher–order properties' – as, for example, the property of being red, or redness, has the second–order property of being a colour–property. In view of this, one may wish to characterize an 'object' more precisely as being an entity which bears properties but which is not itself borne by anything else.
>
> ...
>
> An object is a property–bearing particular which is not itself borne by anything else: in traditional terms, it is an individual substance. A Universal (at least, a first–order Universal) is a property conceived as a "repeatable" entity, that is, conceived as something that may be borne by many different particulars, at different times and places.

It is important to note that Universals, as Lowe defines them, are causally inert. Lowe says:

> ... it seems that only particulars can participate in causal relationships and that an object participates in such relationships in different ways according to its different properties.

Universals, in that they do not refer to a single object are sometimes termed "Abstract Objects" [47]. Lowe gives three main conceptions of abstract objects. First, an abstract object is an object that does not have a specified space–time location. The second conception is that an abstract object does not exist by itself, but is an abstraction of one or more concrete objects. Either of these two conceptions lead to some problems. The non–spatial description of abstract objects leads to problems in an attempt to arrive at a hylomorphic characterization of Universals that are instantiated as a physical process. The "morphic" aspect of a Universal may be without coordinates, but the "hylo" aspect does involve the coordinates of the instantiation of this property, since each instantiation is different. The second concept is problematic as an attempt to establish a Causally Active Metaphysical Realism for the Universals, since this implies they lack the ability to enter into causal relationships.

Lowe credits Frege with the third major conception of abstract objects through the use of equivalence relations. Hale and Wright describe it this way [37]:

> Standardly, an abstraction principle is formulated as a universally quantified biconditional — schematically: $(\forall a)(\forall b)(\Sigma(a) = \Sigma(b) \iff E(a, b))$, where a and b are variables of a given type (typically first- or second–order), Σ is a termforming operator, denoting a function from items of the given type to objects in the range of the first–order variables, and E is an equivalence relation over items of the given type.

Frege gives an example [28] in terms of the concept of parallel lines. Line a is parallel to line b if the directions of the two lines are identical: $Dir(a) = Dir(b) \iff a$ and b are parallel. This way of considering abstract objects applies naturally to numbers. Frege, citing a principle of Hume, describes the concept of number through an equivalence relation: The number of F's = the number of G's if and only if there are just as many F's as G's.

This gives us a notion of an abstract object in terms of a function, which is easier to relate to quantum mechanics. In accordance with the discussion above, a *Universal* is the equivalence class of the output of a function U from a domain D to a range R where the equivalence relation E is as follows: for any two elements of $x, y \in D$, xEy is true if and only if $U(x) = U(y)$. In the first order case, *Particulars* form the domain of the function. The application of the function is termed an *Instantiation of that Universal*. Each Universal instantiates a *Property*, which is the range of the function. And a *Fact* refers to the output of the function for that given instantiation, where these Facts impose an equivalence relation on the set of Particulars[2].

Using this formalism, we claim that instantiation is more fundamental than the Universal that it instantiates. The act of instantiation is prior the existence of the Universal and the existence of the Universal is contingent on the process of instantiation. This is not an unusual position in metaphysics: a number of people such as Armstrong [6] [8], Lowe [49] and Juvshik [40] have expressed the idea that truth-makers and states of affairs are ontologically prior to the Universals that they instantiate.

Considering the process of instantiation as fundamental leads to the inclusion of process metaphysics in combination with substance metaphysics as a better way of describing the world than either alone. The resultant ontology contains both static substances and dynamic processes, where the action of instantiation can be considered to be an "object". Although Frege's notion of an equivalence relation is an abstract object, the equivalence is only established through the act of instantiation, since by definition, the objects $x, y \in D$, are equivalent by the relation xEy only if the instantiation process $U(x) = U(y)$ has been executed.

Seibt's General Process Ontology [59] [58] [60] is an example of this viewpoint. She writes "General processes are independent, individual, concrete, spatiotemporally extended, non-particular, non-countable, determinable and dynamic entities". She applies General Process Ontology to Quantum Field Theory, but in a fashion different from the approach given here. In particular, Seibt describes the "Myth of Substance", instead of

[2] Note that Properties are often considered to be possessed by an object or not, such as saying "the ball is red". In the formalism of this paper, this is a Boolean function whose Fact is either the Boolean value *True* or *False*.

considering a combination of both substance and process.

The combination of substance and process ontology can be seen in formal systems. The Predicate Calculus [44] is a formalization of mathematical reasoning in terms of substance metaphysics. The Universe of Discourse is a set of concrete objects, where both Predicates and Functions are abstract objects (Properties) expressed as subsets of the Universe of Discourse (or its Cartesian products). In contrast, the General Recursive Functions [55] have both objects (the integers) and processes (functions)[3]. Both formalisms are effectively equivalent, but their expression and application are completely different.

In discussing metaphysics in relation to quantum mechanics, the entities under consideration are often limited to those which have a physical existence. This is referred to as a "primitive ontology". Allori [4] describes it this way:

> The main idea is that all fundamental physical theories, from classical mechanics to quantum theories, share the following common structure:
>
> 1. Any fundamental physical theory is supposed to account for the world around us (the manifest image), which appears to be constituted by three–dimensional macroscopic objects with definite properties.
> 2. To accomplish that, the theory will be about a given primitive ontology: entities living in three–dimensional space or in space–time. They are the fundamental building blocks of everything else, and their histories through time provide a picture of the world according to the theory (the scientific image).
> 3. The formalism of the theory contains primitive variables to describe the primitive ontology, and nonprimitive variables necessary to mathematically implement how the primitive variables will evolve in time.
> 4. Once these ingredients are provided, all the properties of macroscopic objects of our everyday life follow from a clear explanatory scheme in terms of the primitive ontology.

In contrast, we shall expand the classes of objects in the primitive ontology to include the instantiation of Atomic Universals as processes. We extend the ontology as follows. The instantiation of Atomic Universals will be used as the fundamental explanation of the Measurement Problem. The act of measurement, at this fundamental level, makes the

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[3] For example, in computer science the formalisms equivalent to the General Recursive Functions are Turing Machines or the specification of computers as collections of silicon gates. It is interesting to note that Complexity Theory discusses space-time tradeoffs in the costs of computation, which is essentially trading off substance (memory size) and process (computation time).

abstract objects of metaphysics — expressed as process — into causal participants. This extends the primitive ontology upon which scientific theory is grounded.

Related to the question of Universals is the notion of *Information*. We shall consider information from a metaphysical standpoint. Note that, although information requires a physical medium for its transmission, it exists as a configuration of abstract objects. That is, information is composed of Facts that are the instantiation of Universals.

This is an abstract definition of information, in that it does not address how information is stored or transmitted, nor how it is quantified. Describing information in terms of metaphysics, we are focusing on the information itself and, depending on the Property being instantiated, what the information means. How these fundamental units of information are combined and interpreted will not be gone into detail in this paper[4]. But we will discuss why information has meaning.

As Lowe mentioned above, Universals are considered to be causally inert. We are claiming that some Universals are causally active, in the sense that their instantiation is a physical process independent of a mental act, that causes other things to happen. The output of the process is information. This information itself then proceeds to affect other things as a consequence.

The next section gives some salient points of a variety of major interpretations of Quantum Mechanics.

3. Quantum Mechanics: The Measurement Problem

The way that abstract objects are related to physical objects depends on the possible interpretations of quantum mechanics. One of the best known is the Copenhagen Interpretation. There are other well–regarded interpretations: we shall present a number of them, in the approximate order of when they were first published.

Most of the differing interpretations of Quantum Mechanics have something to say about the Measurement Problem. Although these interpretations give different explanations of the measurement problem in terms of physical processes and/or physical intuition, there are some underlying metaphysical properties of quantum mechanics that are inherent in the measurement process and therefore common to all interpretations. We shall introduce the Measurement Problem in terms of the Copenhagen Interpretation, then discuss how the other interpretations handle it.

3.1. The Copenhagen Interpretation

[4] This viewpoint is intermediate between information as defined by Shannon [61] which is more about how information is carried by a medium, and Generalized Representational Information Theory of Vigo [64] [65] which is about how information is structured and combined.

The Copenhagen Interpretation (and its variants) is generally regarded as the most popular interpretation of quantum mechanics. This viewpoint started with Bohr and Heisenberg who were working together in Denmark. There is some question as to how much Bohr actually agreed with the Copenhagen Interpretation as it came to be known [35]. The term was first used by Heisenberg [38]. The major principles of the Copenhagen Interpretation are as follows:

- A system is described by a state vector in a Hilbert space. The state vector changes in one of two ways:
  - The state vector changes continuously through the passage of time, according to the Schrödinger wave function.
  - The state vector changes discontinuously, according to probability laws, if a measurement is made. This is termed *Wave Function Collapse*.
- *The Born Rule*: The probability of the outcome of a measurement is given by the square of the modulus of the amplitude of the wave function.
- *The Uncertainty Principle*: It is not possible to know the value of all the properties of the system at the same time if the properties do not commute.
- *The Complementarity Principle*: "Evidence obtained under different experimental conditions cannot be comprehended within a single picture, but must be regarded as complementary in the sense that only the totality of the phenomena exhausts the possible information about the objects." Bohr [68] For example, in the double slit experiment, an electron could show either a particle or wave–like nature depending on the setup of the experiment.
- *The Correspondence Principle*: The quantum mechanical behavior reproduces classical behavior in the limit of large quantum numbers.
- *The Quantum to Classical Divide*: "However far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms." This generalization of the Correspondence Principle was mentioned by Bohr as part of Complementarity, and is considered as such, but it comes from a different aspect of Metaphysical Realism than the Complementary Principle. So it is listed separately and given its own name.

The main concept we shall consider here is the *Measurement Problem*.

A measurement is related to an observable. An observable, such as momentum or spin can be represented as an operator in a vector space [56]. It was defined by Dirac [21] (the *Projection Postulate*) as:

> A measurement always causes the system to jump into an eigenstate of the dynamical variable that is being measured, the eigenvalue this eigenstate belongs to being equal to the result of the measurement.

To relate measurement to metaphysical Universals, recall that we are defining Universals in terms of equivalence relations. Equivalence relations for quantum mechanical measurements require conjugacy classes: equivalence relations based on eigenvalues are insufficient because many measurements yield the same values [71]. Therefore when we relate measurements as eigenvalues to an instantiation of a Universal as a Fact we are referring to the conjugacy classes associated with the operator the measurement is derived from.

The interpretation of wave function collapse has been subject to debate from the time it was first identified. One interpretation came from Heisenberg, von Neumann and Wigner.

Heisenberg, in his 1927 paper *The Physical Content of Quantum Kinematics and Mechanics* [68] describes wave function collapse as an act of observation. This concept was further incorporated into the mathematical formulation of quantum mechanics by John von Neumann, in his 1932 work *The Mathematical Foundations of Quantum Mechanics* [66]. von Neumann defines two processes in Quantum Mechanics: the first process is the collapse of the wave function during a measurement and the second process is the development of the wave function in time according to the Schrödinger equation. For a measurement, he made the distinction between the observed system and the observer, and discussed the boundary between them. He noted that the subjective consciousness of the observer plays a part in the observation made during the measurement.

This viewpoint was extended by Wigner in the argument that has come to be called *Wigner's Friend* [68]. Wigner makes the argument that if he asks a friend if that friend has seen a physical phenomenon or not, such as a flash of light from an atomic process, then since that event was in the past and the person has made the observation, the interaction of the friend and physical object is either in one or the other state corresponding to the observed outcome, and not a superposition of the two outcomes which would be the case for a measuring apparatus:

> If the [measuring apparatus] is replaced by a conscious being, the wave function [as a superposition] appears absurd because it implies that my friend was in a state of suspended animation before he answered my question.
>
> It follows that the being with a consciousness must have a different role in quantum mechanics than the inanimate measuring device.

Other physicists did not agree with the necessity of consciousness. Bohr is a case in point. In Bohr's view, the process of going from the quantum realm to the classical realm must be considered in the context of both the object being measured and the measuring apparatus. The concept of wave function collapse still plays a part in this interpretation, and is considered a fundamental process. But there is no need to postulate an observer. In this viewpoint, there is no effect from outside on what is measured. Instead, the measurement is just a result of the interaction of the measurement apparatus and the object being measured, no more.

The Quantum to Classical Divide addresses the problem of the interface between the quantum level and classical measurements. But this leaves open the question of what the classical measurements mean. Bohr claims that they are derived from sense perceptions. But there is more to it than that, since the bare fact of being a perception does not provide the meaning of the perception. When Bohr refers to classical observations, they are usually in terms of the parameters that make up classical physics — e.g. mass, motion, charge and position — abstract objects that may have begun as sense perceptions, but are now part of a physical theory that has been built up since the time of the ancient Greeks, and systematized in the Enlightenment.

3.2. Pilot Wave Theory

In contrast to the Copenhagen Interpretation, there is the Pilot Wave Theory of Bohm [12] [13] and de Broglie.

Bohm's pilot wave is a type of "hidden variables" theory. That is, he postulates that the Schrödinger Wave equation is an incomplete description of reality at the quantum mechanical level. In Bohm's viewpoint, each particle in the universe has a defined position. The motion of each particle is guided by the Schrödinger Wave equation. This is the "pilot wave" in that it guides the particle.

An important difference between Pilot Wave Theory and the Copenhagen Interpretation is that Pilot Wave Theory is deterministic, whereas the Copenhagen Interpretation appears to be essentially random when it comes to the wave function collapse. The two approaches though, are thought to give identical results[5].

3.2.1. Everett's Many Worlds Interpretation

In Everett's Many Worlds Interpretation [27]. there is no Process 1 (wave function collapse). Instead of the wave function being collapsed, the state of the system becomes entangled with the observer. This interpretation was revived in the 1970's by DeWitt as the Many Worlds interpretation, where different possible outcomes of a measurement produce

[5] This may be changing. Although the Pilot Wave Theory was criticized by Englert, Scully and Süssmann [26] as resulting in surrealistic particle trajectories, recent experimental results by Kocsis et al. [45] and Mahler et al. [50] show that these trajectories can actually be observed.

different copies of the universe[6].

Everett writes “Thus with each succeeding observation (or interaction), the observer state ‘branches’ into a number of different states. Each branch represents a different outcome of the measurement and the corresponding eigenstate for the object-system state. All branches exist simultaneously in the superposition after any given sequence of observations.” This is reflected in the memory of the observer: “The ‘trajectory’ of the memory configuration of an observer performing a sequence of measurements is thus not a linear sequence of memory configurations, but a branching tree, with all possible outcomes existing simultaneously in a final superposition with various coefficients in the mathematical model.”

Although Everett’s interpretation denies that wave function collapse occurs, it is still true that there is a measurement. These measurements are recorded by observers that are purely physical systems with memories to record the measurement.

3.2.2. Decoherence

A number of current interpretations of quantum mechanics use the phenomenon of decoherence to explain the measurement problem: why we see classical behavior (the eigenvalues of the quantum state) instead of the quantum superposition of states. This approach has been pioneered by H.D. Zeh [73] and W.H. Zurek [74] and further developed by researchers such as Schlosshauer [57].

Environmental decoherence comes about as a quantum system interacts with the environment in which it is situated. This process is termed “Einselection” (environmentally induced superselection), where superselection is the condition that eigenstates can be selected [34] by any observable, not just a Hamiltonian operator.

The consequence of Einselection is that, given the joint density matrix for the system and the environment, the off–diagonal elements of the matrix go to zero after interactions with the environment, regardless of the environmental basis. Although the system started out as a superposition of states, the interaction with the environment leads to the superposition being part of the system–environment joint state, and the appearance of the system alone is as if it were a classical ensemble of states.

A related issue is the preferred pointer basis. Schlosshauer [57] describes the preferred basis problem this way: Let $|\psi\rangle$ be:

$$|\psi\rangle = \sum_n c_n |s_n\rangle |a_n\rangle$$

6 It is interesting to compare Everett’s interpretation to Lowe’s Modal Realism. [46]. Whereas Lowe postulates that the different worlds exist independently, Everett provides a mechanism where they branch off from each other. We shall not consider modal metaphysics in this paper.

The preferred basis problem arises because it is possible that, given a new set of basis vectors $|s'_i\rangle$ and $|a'_i\rangle$, $|\psi\rangle$ is also:

$$|\psi\rangle = \sum_n c'_n |s'_n\rangle |a'_n\rangle$$

such that the same post measurement state could appear to correspond to two different measurements of observables $\hat{A} = \sum_n \lambda_n |s_n\rangle\langle s_n|$ and $\hat{B} = \sum_n \lambda'_n |s'_n\rangle\langle s'_n|$ even though $\hat{A}$ and $\hat{B}$ do not commute. But the simultaneous measurement of two non–commuting observables is not allowed in quantum mechanics.

This problem is also resolved in decoherence through einselection. The interaction between the apparatus and the surrounding environment singles out a set of mutually commuting observables. The preferred pointer basis is the basis in which the system–apparatus correlations $|s_n\rangle|a_n\rangle$ are left undisturbed by the subsequent formation of correlations with the environment.

3.2.3. Consistent Histories and Decoherent Histories

Consistent Histories is an approach introduced by Griffiths [36]. Although measurements do not play a part in this interpretation, there are "events". Joint probabilities are computed on a series of events (a history). It is required that the events be consistent, in the sense that they commute.

Consistent Histories was developed further by Gell-Mann and Hartle [32], in what is termed Decoherent Histories. This approach uses decoherence in the context of consistent histories to explain the emergence of classicality from quantum mechanics. The fine-grained history of the full set of operators is grouped into a coarse-grained structure upon which the process of decoherence applies, leading to our concept of a classical domain. They suggest that human observers are examples of an "information gathering and utilizing system" (IGUS) that evolved to exploit the quantum regularities in some particular quasi-classical domain, giving a predictive power to observations.

3.2.4. Ghirardi, Rimini, Weber Collapse Theory

The Collapse Theory of Ghirardi, Rimini and Weber [33] takes the process of wave function collapse literally, and attempts to quantize it. Given that a quantum system can be a collection of particles in a superposition of states, collapse theory postulates that individual particles sometimes collapse to a particular location out of a superposition of possible locations. Although the chance of an individual particle collapsing is very low, this will happen in a macroscopic system almost instantaneously, leading to a measurement.

3.2.5. Transactional Interpretation

In the Transactional Interpretation [17], the ψ and ψ^* wave functions are presumed to move in opposite directions in time. According to Cramer [18], “Any quantum event is a ‘handshake’ executed through an exchange of advanced and retarded waves”. These are referred to these as the Offer Wave and the Confirmation Wave. Kastner points out [43]: “In TI, these Offer Wave/Confirmation Wave encounters are called incipient transactions. If we add all the incipient transactions, we clearly have the density operator representation of von Neumann’s Process 1.”

3.2.6. Quantum Bayesianism

According to Quantum Bayesianism [29], quantum mechanics is more about information – a measurement is the updating of subjective probabilistic beliefs about a system. Fuchs says [30]: “QBists opt to say that the outcome of a quantum measurement is a personal experience for the agent gambling upon it. Whereas Bohr always had his classically describable measuring devices mediating between the registration of a measurement’s outcome and the individual agent’s experience, for QBism the outcome just is the experience.”

We will now discuss the Problem of Universals in terms of the Measurement Problem of Quantum Mechanics.

4. Universals in the Ontology of Quantum Mechanics

There are two parts to the question of Universals in the context of Causally Active Metaphysical Realism. The first part is the process by which the Universals come to be associated with physical objects. The second part is the nature of Universals themselves. We shall answer these questions through the process of Measurement in Quantum Mechanics.

Given the definitions of Universals and Properties as described in Section 2, we can state the following principles about Facts about physical objects[7]:

- A Fact occurs at some discrete point in space. It is not continuous, but localized.
- A Fact comes into being relatively quickly. It is localized in time.
- A Fact is universal for all space and time.
- A Fact is universal for all observers.

[7] These claims certainly cannot be applied to Universals that are pure concepts, such as truth and beauty. We will argue that these other Universals arise from concepts about physical objects.

- A Fact captures only one aspect of a state of affairs. It is conceptually localized.

So a Universal generates Facts about physical objects that are eventually the same for all observers. Otherwise, the physical evidence of the result would not be fixed in time and space: the photodetectors of a physics experiment would give different readings for different observers. But different observers do not have to know the same Facts at the same time. We are limited by the speed of light and the bandwidth of our information systems.

Regardless of the particular interpretation of the Measurement Problem, it is obviously true that what the interpretations have in common is that a measurement occurred. Measurements record some property of the system – they generate information that has meaning. So if a measurement has been made, it results in a Fact. This Fact is universal to all observers, at different times and places. It is still a Fact even if there were no observers, as long as there was some physical record of its particular value, even just a transient record. Otherwise, there can be no possibility of any kind of universal information or knowledge in the universe. This must be true regardless of the interpretation — the measurement may be due to wave function collapse, decoherence, Many Worlds, or any other process.

Regardless of how to explain the Measurement Problem, any Fact that is true about some physical system is based on a measurement. That is, measurements have the following properties:

- A measurement is made of a system localized in time and space.
- A measurement is a process that yields a Fact as its outcome.
- A measurement captures only one aspect of a Quantum Mechanical state.
- A measurement is universally true, eventually.

The main claim of this paper is that Causally Active Metaphysical Realism gives a physical basis to the existence of the Facts that are generated by metaphysical Universals. This physical basis can be found in the process of measurement in Quantum Mechanics. The two realms – physics and metaphysics – form a dualism where both substance and process form an interdependent part.

The essential problem with the measurement problem is that a quantum mechanical system is a thing but a measurement is an idea. The measurement problem is usually discussed in terms of the experimental determination of properties of objects but it is deeper than that. The object exists and has properties regardless of whether they are measured or not. But we have no knowledge about the properties of the object without measurements.

So what is the meaning of measurement in terms of Universals? Qualitatively, measurement is the process of abstracting some Property from an object. The instantiation of Universals as the output of a measurement means that these Properties are not fundamental objects — they are the results of processes that are themselves fundamental.

This is the justification for considering measurement as an ontologically fundamental process. The resultant abstract object supervenes on the process. Put another way, measurements are the fundamental truthmakers for the class of Universals that instantiate physical Facts, the ground truth of physics.

Rephrased in terms of Quantum Mechanics, a measurement is a process of instantiating a Universal, which will be termed a *Hylomorphic Function*. This function has an input — a quantum state at a given time and place — and an outcome that is an eigenstate with an associated eigenvalue.

The measurement has an associated observable operator. The operator forms a conjugacy class on the set of possible measurements. Using the definition of a Universal as Frege's concept of an equivalence relation, the operator that specifies the measurement instantiates a metaphysical Universal. The act of measurement executes the Hylomorphic Function, resulting in a Fact — a particular instantiation of a Universal at that time and place. This gives a physical explanation for Causally Active Metaphysical Realism.

John Stewart Bell, in *The Theory of Local Beables* [11] makes the distinction between beables and observables, where observables are objects derived from the beables and beables are entities that have a physical existence. He questions the physical reality of observables, in that he thinks that the beables form a primitive ontology from which the observables can be derived. Bell prefers to focus only on beables [11]: :

> In particular, we will exclude the notion of "observable" in favour of that of "beable". The beables of the theory are those elements which might correspond to elements of reality, to things which exist. Their existence does not depend on 'observation'. Indeed observation and observers must be made out of beables.

Instead, we need both. In Bell's terms, the hylomorphic functions are the process of generating an observable from a beable. Causally Active Metaphysical Realism implies that observables do not exist because of beables — they exist in their own right. The beables are composed of physical entities, and the observables are composed of the instantiation of Universals that are the results of quantum measurements.

Observables exist as much as beables do. If they were dependent upon beables, the question can be reasonably posed: how does the mere fact that beables exist give rise to observables? There is nothing in modern physics that describes how beables create observable Facts. Admittedly, the claim that observables, as the output of hylomorphic functions, exist independently of beables also does not, by itself, answer how observables come to be. This is a problem that physics has yet to definitively address. But establishing hylomorphic functions as independent physical processes brings this problem into relief.

Substance metaphysics is captured in Schrödinger's equation. Process metaphysics is the process of measurement. Facts are created by a process, a Hylomorphic Function. The different interpretations of Quantum Mechanics give a different physical explanation for how the Fact is generated, but they do not explain the Fact itself. They do not explain the creation of abstract objects.

With this viewpoint of Hylomorphic Functions, we see the resolution of certain puzzles bedeviling different interpretations. In particular, there is no need to split the universe into a system and observer, or the tripartite system, observer and environment. For example, Smolin [62] says this about the system – observer split: "The interpretational difficulties with quantum cosmology arise because the conventional interpretations of quantum theory require that the quantum state description be applied only to subsystems of the universe. The interpretation of the theory requires the existence of things which are in the universe but outside of the system described by the quantum state, including the measuring instruments, the clocks that give meaning to the Schrödinger evolution and the observers." The notion of Hylomorphic Functions does away with that. Instead of two subsystems, there is a *System* (a substance) and a Hylomorphic Function (a process) that generates a *Fact* about the System without reference to an observer. Facts exist by themselves as causally active abstract objects. They do not require an observer to exist. There can be zero, one, or many observers of the same Fact.

For many interpretations, this split has been so hard to define that sometimes it is argued away. Schlosshauer [57] says: "As long as the universe is not resolved into individual subsystems, there is no measurement problem." But measurement occurs all the time, regardless of the observer. The measurement problem exists because we have information with meaning.

If a Fact is never recorded, does it exist? Probably not – otherwise there would be no information. A measurement must be recorded somehow. But does this do away with the necessity of defining a process? No, because the process of creating Facts is not part of physics as we currently know it, since physics has no formal mechanism to define the meaning of information. Not the amount of information, or the physical manifestation of information, but the meaning.

A measurement is causally active because the value of a measurement affects other processes by transferring information to those other processes, such as in Heisenberg's description of a light measurement of an electron orbit [68]. This instantiation has a defined time and place, so any Fact that is the result of a hylomorphic function can only be true at that time and place.

Can there be knowledge without an observer? Dirac describes the Projection Postulate without reference to an observer. A measurement could simply be the recording of information. This can happen without a consciousness being present. This is in contrast to the Wigner's friend argument: a Fact is instantiated whether there was a consciousness there to experience it or not. For example, a Stern–Gerlach experiment could possibly arise naturally with suitably situated natural lodestones and a material that reacts to the particles passing through the lodestones. Consciousness is not required for wave function collapse – the act of measurement is sufficient, regardless of how the measurement came about. This is discussed further in Yu and Nikolić [72] where an experiment is described that has measurement without observers.

This is in contrast to Quantum Bayesianism. As Fuchs, Merman and Schack [31] put it: "The disagreement between Wigner's account and his friend's is paradoxical only if you take a measurement outcome to be an objective feature of the world, rather than the contents of an agent's experience. The paradox vanishes with the recognition that a measurement outcome is personal to the experiencing agent."

This is just not so. For example, a measurement about a quantum system can be captured in the position or velocity of an electron traveling away from the system. This electron has taken on these properties because of some particular property of the system it is leaving. You do not need a human agency to make this possible. You don't even need an electron detector to make this possible. This property is inherent in the electron. This is information that can be transferred to another quantum system, and can eventually become part of the information of a classical measurement apparatus. But the apparatus does not make the information come into being. It only transmits that information.

Note that due to entanglement, Facts are not necessarily independent. Actually, since they are causally active, entanglement is always a possibility.

4.1. Atomic Universals

A measurement can be made of a quantum mechanical system of arbitrary complexity. We need to consider the notion of an *Atomic Universal*. This is a fundamental physical observable, such as position, momentum, velocity or spin. An Atomic Universal is a Property that is fundamental in the sense that it cannot be reduced to another Property or combination of Properties. Metaphysically, it is a quantum. Here, the distinction made by Bell of a local beable is worth noting. A local beable can be assigned to some bounded space time region. This locality is also a fundamental aspect of an Atomic Universal. As mentioned, both Facts and measurements are localized. The Atomic Universals form a primitive basis for the rest of the Universals that are composed of them. A Fact that is the instantiation of an Atomic Universal will be termed an *Atomic Fact*.

It can be argued that the Atomic Universals form the basis for natural classes, in the sense of Armstrong [6][8]. Armstrong claims that natural classes are determined by scientific reasoning. The hylomorphic functions provide the physical explanation for this.

So the hylomorphic functions complete the ontology started by Allori. The primitive

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[8] Eddon [23] uses the term fundamental, or natural, properties

ontology as currently conceived describes the properties of physical reality in their most basic units. The hylomorphic functions are the part of the theory describing the process by which physical entities give rise to information. The Atomic Universals are as fundamental to describing the abstract information of reality as the primitive ontology of Allori is to describing the physical substance.

Contrast this to Kastner's Possibilist Transactional Interpretation (PTI) [43] [42].

> [Q]uantum entities described by state vectors must have a different ontological status. In PTI they are viewed as physical possibilities or potentiae, just as Heisenberg suggested... It is a fundamental feature of quantum mechanics that the object of observation is always an actual outcome, and never a superposition of potential outcomes. Thus, one cannot 'directly observe' potentiality, but rather only infer it from the structure of the theory.

The difference between this approach and hylomorphic functions is that PTI considers potential outcomes as ontologically basic, but with hylomorphic functions, the process itself is ontologically basic.

Consistent histories [32] has the concept of coarse grained and fine grained histories to explain the emergence of quasi-classical domains. The IGUS chooses the coarse graining and thus the domain. Instead, we make the claim that coarse graining arises naturally out of the nature of Atomic Universals, which are the fine grain.

It is also necessary to emphasize that the mere existence of a Fact is only one aspect of a Quantum Mechanical system. A related problem is how we arrive at the selection of a particular Fact for a particular measurement. In "Against Measurement" [10] Bell says: "the measurement act 'collapses' the state into one in which there are no interference terms between different states of the measurement apparatus." This process is the selection of an ideal. But it also occurs in other interpretations: for example, in decoherence, the process of measurement is the reduction of the interference terms. The metaphysics of a measurement is that every Atomic Universal is an abstraction of some single concept, not the whole state of the system. It is possible to consider the wave function of the Universe containing all knowledge, but each measurement only contains a single universal. Otherwise it is impossible to have universals – everything would be metaphysically indistinguishable.

The Kochen–Specker theorem shows that it is not possible to instantiate all properties of a system simultaneously. This is consistent with the claim that only one hylomorphic function can be instantiated at a time. This means that complementarity is inherent in hylomorphic functions.

Note that complementarity is not just a duality, like that of wave and particle. There are as many possible properties as there are hylomorphic functions. A measurement is the choice of a single Property out of all of the possible Properties to instantiate. But the choice of one Property means the others are ignored[9]. The property instantiated may be because of the intentional setup of an experiment or it may be because of a naturally occurring situation. But we end up with a single Fact. The System that is characterized by the Fact keeps on developing according to the Schrödinger wave equation, so we will have other Facts at other times. But we also can only know a limited amount of knowledge about a system at any given time. As we get new Facts, the system evolves and the old Facts become invalid.

This brings up the question of more complex Universals. How universal are Universals such as Redness, Truth, or the Number One? It could be argued that the Universals we recognize are what they are because we are human and these are what humans recognize — they are just brute facts. Instead, we claim that concepts such as these can be considered to be composed of Atomic Universals, similar to the way physical objects are composed of atoms. The Atomic Universals are not contingent on human thought — they are part of the fabric of reality. But the concepts we recognize are formed from our existence as human beings. This means that there is a basic ground of Causally Active Metaphysical Realism when it comes to Universals, that also allows for a metaphysical nominalism, if Trope Theory [70] [52] is true.

For example, Universals that are relational operators, such a A *is heavier than* B are not fundamental Properties. Atomic Universals can only be simple quantities. It is difficult to claim that the relationship between two Atomic Universals can come about without a mental act that compares the two. This is the case with Johannsen [39] who considers relations that depend on collections of scattered quantities. Eddon [24] also discusses a definition of relation based on the work of Mundy, that involves predicates of variable degree. In both of these cases, the relation depends on the ability to keep a number of more fundamental concepts in mind – a problem that does not arise with hylomorphic functions that instantiate a single Property.

This composition of Universals is constrained by physical necessity. So, for example, the taxonomy of Universals composed of hylomorphic functions is constructed in the same sense that an electron is part of a transistor, and transistors combine to form electronic circuits. Each step of the way, there is the notion of electrons, but they can be combined to form more complex notions according to the constraints of the physical processes. The

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[9] Cramer [17] points out that in the classical regime, electrical pulses can be represented either in the time domain as a set of voltages varying as a function of time, or in the frequency domain as a continuous set of Fourier components, i.e., a set of voltages varying as a function of frequency. These representations have exactly the Bohr–Heisenberg complementary relationship and exhibit their own "uncertainty principle". This reflects the point that the nature of Universals requires that a choice must be made of which Property to consider at any given time. This is part of the nature of metaphysics, not specific to a particular domain of physics.

emergence of more complex Universals is not arbitrary, but based on the nature of the physical world.

This means that the laws of nature are not fundamental. To quote Armstrong [7]: "It remains true, though, that your average law of nature that has some claim to be fundamental will be a functional law that connects two or more quantities. This in turn means that a scientific or a posteriori realism about Universals will have to concentrate particularly on Universals of quantity." Since laws of these types are relational, they can never be ontologically fundamental.

Bohr considered a quantum measurement to consist of both the phenomenon being measured and the apparatus measuring it. This viewpoint has been carried into Pilot Wave Theory. Durr, Goldstein and Zanghi [22] explain the physical properties of quantum observables as follows:

> The best way to understand the status of these observables — and to better appreciate the minimality of Bohmian mechanics — is Bohr's way: What are called quantum observables obtain meaning only through their association with specific experiments. ... Information about a system does not spontaneously pop into our heads, or into our (other) "measuring" instruments; rather, it is generated by an experiment: some physical interaction between the system of interest and these instruments, which together (if there is more than one) comprise the apparatus for the experiment. Moreover, this interaction is defined by, and must be analyzed in terms of, the physical theory governing the behavior of the composite formed by system and apparatus. If the apparatus is well designed, the experiment should somehow convey significant information about the system. However, we cannot hope to understand the significance of this "information" — for example, the nature of what it is, if anything, that has been measured — without some such theoretical analysis.

But Causally Active Metaphysical Realism brings this notion into question. This analysis does not explain why there are certain Universals and not others — it does not explain the source of the Universals. Seen from the viewpoint of Causally Active Metaphysical Realism there is a circular argument in this view: the experiments represent Universals that are not necessarily Atomic, but they give rise to the Atomic Universals via quantum measurements. This problem is similar in character to the argument that Kant had used to claim that there must be *a priori* knowledge of physical reality that he defined in the *Prolegomena* [41].

We measure what we ask for. What we ask for is a property of nature. The properties of nature are what we measure. This is circular. Instead, what we ask for is composed of more fundamental physical measurements, and the hylomorphic functions associated with these fundamental measurements produce the result of our experiments. We are not free to create fundamental properties from scratch through the setup of our experiments. Instead, the way we set up an experiment will elicit certain fundamental properties.

The Atomic Universals are fundamental and a priori. They form our ontological basis. From this basis our thoughts are constructed, and this determines what we ask for. Put another way, the reason we set up an experiment in a certain fashion is because we have an idea in mind about the nature of what we want to measure. But this idea has to come from somewhere. It arises out of the hylomorphic functions that form the basis of Metaphysical Realism, not just our conceptual structure.

The problem is, why do we have the Universals we have and not others? Why is there some particular set of Atomic Universals and not just an arbitrary or infinite number of different Universals? Why we have the Atomic Universals we have is a question that needs to be explored. The reason why they are what they are is unknown. Perhaps the Atomic Universals aren't discrete but live on some higher manifold [71].

It has been mentioned by Ney [4], among others, that particle position is the only determinate observable — it is the single measurement that has metaphysical meaning[10]. This may be so, but it leaves open the question of where the other properties, such as charge, velocity, momentum, spin, etc. come from. It could be that, similar to the process where quarks form protons and neutrons which combine with electrons to form the elements of the periodic table, the measurement of position gives rise to the Atomic Universals that compose the Universals we as humans know. But the claim that position is fundamental is unlikely, unless we can come up with a process by which we can show how the other Atomic Universals are combinations of position measurements. In classical physics we do have a distinction between basic properties such as mass, distance and time and other observables such as velocity and force. This taxonomy of abstract objects likely carries into the quantum realm in some sense. Daumer, Dürr, Goldstein, and Zanghì [19] argue against a naive realism where the world is just what it seems, showing that it is possible to mathematically derive some properties, such as spin, from more fundamental properties, such as position. Yes, but this does not answer the question of why spin is a fundamental concept. All that has been accomplished is to create a theoretical scaffolding on the physical level that covers the underlying structure on the conceptual level.

The Atomic Universals are the essential preferred basis vectors for quantum measurements. Vanni and Laura [63] argue that the basis of any measurement is uniquely identified by the physical process involved in the measurement without recourse to decoherence. As Schlosshauer notes: [57] "The appearance of 'classicality' is therefore grounded in the structure of the physical laws." This means that the physical processes

10 It is sometimes stated that position is the universal preferred basis, such as for collapse theories like GRW [57]

involved in measurement determine the preferred basis.

The reason why a hylomorphic function is a process that is different from objects is not due just to the simple act of measurement. Instead, it is due to the fact that after the measurement, we end up with properties as abstract ideals. Substance physics alone is hard pressed to explain the abstract ontology: why we have the set of preferred bases that we do, or alternatively, why we have the set of hylomorphic functions we do. There is nothing in decoherence that allows us to derive a fundamental primitive ontology of measurements. Physics just goes from state to state, but a hylomorphic function generates a Universal Fact. It is not the action alone that counts – it is also the result. A process is composed of an input, a transformation and an output. The output is a fundamental part of the process. In physics, things just are. In metaphysics, things are known.

This problem also comes up in Quantum Information Theory. For QIT to work, we need an a priori definition of states. See for example, Cerf and Adami [15] discuss the Stern–Gerlach experiment. The analysis is given in terms of spin states. Why these states and not others? QIT only works if there is a set of Atomic Universals. Without this, there would be no set of states to define and the whole world would be smeared out. Put another way, correlations are defined over a universe of discourse, which comes from the ranges of hylomorphic functions.

4.2. Non-Causal Inferences

Whether all abstract Universals are causally active is a matter of their logical distance from the Atomic Universals. Although all Universals are composed of Atomic Universals, this does not mean that they are all causally active. In classical physics, the Universals that form its ontological framework are higher level Properties that are derived from measurements of the underlying physical processes. These properties are the result of a process of logical deduction and mathematical computation. The conclusions that one observer makes can be different from that of another, in contrast to an Atomic Fact, which, being universal, is true for all observers. To distinguish a non–causal deduction from an Atomic Fact, we will refer to it as an *Inference*. Causally active Facts are the same for all observers. Inferences can differ between observers.

Whether or not a Universal is causally active is a binary property. A Universal is either causally active or it is not. Certain causal chains are easy to determine: Fact A causes Fact B, such as a photodetector converting a photon into a current which is sent to a display which converts that Fact into a photon again that reaches an observer's retina. Inferences, such as those composed of relational operators may have causally active Facts as their components, but are not themselves causally active.

A case in point is Schrödinger's cat. Although it is possible to express the cat as a superposition of quantum states, this is an Inference that is subject to a measurement:

looking in and observing the cat. Note that the single atom that triggers the release of the hydrocyanic acid has created an Atomic Fact, but the later determination of the fate of the cat is an Inference. It is composed of the individual concepts that compose it, such as the concept of a cat and what alive or dead means, along with the complex of measurements that determine whether the cat is alive or dead. The measurement of a cat being alive or dead is based on simpler measurements, just like the cat's body is made up of molecules which are made of atoms.

The Afshar experiment [1] [2] [3] is an example of an experiment that combines both causally active Facts and inactive Inferences. The direct observations of which-way information forces other observations to be constrained (pinhole 1 precludes pinhole 2), because the Atomic Universals are limited to a single Fact which is causally active and registered by the photodetector. The information about the waves come from Atomic Facts about the wires, which are causally active, but the conclusion is not active. The location of the wire mesh is part of the setup of the experimental apparatus and is determined by measuring the location of the wires. But the conclusion that the wires do not interfere with the laser light is a causally inactive Inference in the mind, that places no physical constraint on the direct observations made by the photodetector. This means that there is no violation of complementarity – most likely, the measurements of the wires were made even before the lasers were turned on.

This distinction between Fact and Inference must be clearly made. For example, Cramer [17] describes Renninger's gedanken experiment where a sphere of radius R_1 composed of scintillation counters is occluded in part by another incomplete sphere of radius R_2 composed of scintillation counters inside the R_1 sphere. If a particle is randomly emitted from the origin, the initial state can be considered to be $|S(t)\rangle = p_1|E_1\rangle + p_2|E_2\rangle$ where p_1 and p_2 are related to how much the partial sphere occludes the outer sphere. The claim is made that after some time t_2 which would allow the particle to reach the inner partial sphere, if there is no scintillation, the state collapses to $|S(t)\rangle = |E_1\rangle$ for $t > t_2$.

The distinction to be made here is that both state representations are Inferences, and are not causally active, even though they are certainly true. What is missing here are the Facts. For example, what Facts allow us to infer that there was no scintillation? This would seem to imply that an observer of this system was monitoring an information channel connected to the inner scintillation counters, where the measurements received from that channel indicated a negative result. Otherwise, it is not possible to infer that no such scintillation has been received. You need Facts to base your Inferences on.

This is where the "shifty split" of the Quantum to Classical Divide occurs. It is the shift from causally active Facts to causally inactive Inferences. This split is a discontinuous jump, since there is nothing in between causally active Facts and causally inactive Inferences.

5. Experimental Tests

Experimental verification is important because it gives an objective justification about which view of metaphysics is correct. A metaphysics tested by experimentation forms the conceptual underpinning of science.

Since we have made the case that the instantiation of Universals can be causally active, then the process of instantiation of a hylomorphic function and the existence of the resultant Fact is subject to experimental verification, with implications for an expanded viewpoint of physics that involves both concrete objects and abstract processes as ontological objects in their own right. Here are some experimental tests that can give credence to this viewpoint.

5.1. Discovery of Atomic Universals

The discovery of a new Atomic Universal is as likely as a new law of nature. New Atomic Universals are typically classical concepts and new ones would only come about if we were to have new situations that give observations that we would have no way of experiencing up till now. To find new ones, we would have to explore places in the universe that are unfamiliar to us, which can only be described in terms of new concepts.

Note that Atomic Universals are a priori to experience – they are essentially a part of nature and cannot be manufactured. This implies that most common Atomic Universals have already been found, and that any we don't know of yet will be discovered in unknown and surprising ways.

One possible method of discovering new Atomic Universals is through the careful analysis of decoherence. Typically, the matrix representation of the state of a system is established prior to an experiment and contains our expectations of what the experiment will reveal. If the off–diagonal matrix terms do not behave in the way we expect, it may be due to our not knowing that the system had other eigenvalues that we did not take into account, and that the expression of the experimental system needs to be reformulated. This reformulation may result in the identification of previously unknown Atomic Universals. Deutsch [20] suggests some techniques in terms of determining the preferred basis that could be used to construct some experimental tests of this kind.

5.2. Localization of Measurement Items as large as Buckyballs have been shown to have

wave characteristics, in accordance with Schrödinger's wave equation. But individual measurements must occur at a single point in space and time. This means that for macroscopic quantum systems, any measurement is localized to a particular part of the system and does not necessarily apply to the whole system. Experiments can be set up such that macroscopic systems can yield separate measurements at different times and places that do not coincide.

5.3. Afshar Type Experiments Regarding the Afshar experiment: with the distinction between causally active Facts and inactive Information, it is possible to create a whole family of experiments where the causally active Facts force a choice of a particular measurement that precludes another measurement, as in complementarity, but there can be associated, causally inactive Information that can be derived from the Facts but do not further constrain these measurements.

For example, the wires in the Afshar experiment could be replaced by electron beams, which could be shifted from one place to another, based on the which way information from the two pinholes. If the photon comes through pinhole A, the electron beam would be in one of the areas where it is most likely to interfere, and would be moved to be least likely to interfere if coming from pinhole B. The photon could be sent through a mirror to give the circuitry time to shift the beam. This might lead to a situation where complementarity would play a part.

Care must be taken to identify what are true Facts and what are Inferences. It is also important to note that, if an Inference has been made, what actual Facts are used to derive it?

5.4. Inferences from Systems of Atomic Facts For macroscopic systems like Schrödinger's Cat there is a complex evolution in the system that makes it difficult to make observer dependent statements about the system as a whole. But experiments can be set up where a set of Atomic Facts are given, but different Inferences are drawn depending on the subset of Atomic Facts that are used. This is difficult to do for a system the size of a cat, because the measurements that go into determining the life or death of the cat are almost identical for two observers standing side by side. But for smaller systems where there are a handful of Atomic Facts involved, it would be possible for two observers, making inferences on slightly different sets of Facts, to draw contradictory conclusions.

6. Conclusions

In conclusion, hylomorphic functions can be characterized as the process of measurement in Quantum Mechanics.

- This establishes both observables and beables as essential to the basic ontology of Quantum Mechanics. The beables are the physical entities of the basic ontology. The observables are the process of instantiation of Universals.

- Hylomorphic functions are a separate process from the wave function, a measurement that instantiates a Property. But this does not make the wave function deterministic from then on. The instantiation of a Universal is a Fact that characterizes the wave function at this time and place, but the wave function still maintains its indeterminacy due to its other properties.

- Hylomorphic functions give a physical interpretation to Causally Active Metaphysical Realism. This gives us a duality between substance metaphysics and process metaphysics.
- The Atomic Universals are part of the primitive ontology, along with physical objects.
- The hylomorphic functions are not derived from measurements, but are a priori to measurements.
- Atomic Universals are quantities. Any combination of individual quantities is an Inference that is not causal.

It is important to note that, regardless of whatever particular interpretation of quantum mechanics you choose, hylomorphic functions are a reality. It is true that, depending on the interpretation, Causally Active Metaphysical Realism could be either a Platonic dualism or an Aristotelian reality, where the laws of physics determine the objects of reality and the hylomorphic functions instantiate the conceptual qualities of these objects. Whether these two versions of Metaphysical Realism represent different experimentally distinguishable descriptions of the nature of the universe has yet to be determined.

There are a number of concepts that are fundamental to physics and mathematics, such as the existence of integers and reals and the reality of the universal basis of effective computation that is expressed in Church's Thesis. These concepts should be considered to have a basis in hylomorphic functions — their universality has not been disproved, so they probably have a real ontological existence.

To quote Weinstein[67]: "Although many seem to think that the ultimate physical theory will be a quantum theory, it seems to me that it is worth seriously considering the idea that quantum theory is joined at the hip to classical theory, and that further progress in understanding quantum theory will come, not by probing quantum theory proper, but by coming to understand how to move beyond it." This theory is an attempt to combine the metaphysics of classical theory to the physics of quantum theory.

Dualism is the recognition that the objects of the physical world and the objects of cognition seem to be fundamentally different. The hylomorphic functions provide an answer to this. But this still leaves open the question of how the concepts and ideas we think about are composed of Atomic Universals. Although the objects of our perception are composed of Atomic Facts, such as when light impinges on the retina, these make up the total experience of an object such as a chair. But there is still the question of how the identification of an object like a chair is done. This results from a basis of hylomorphic functions — Atomic Facts that combine to form qualia as observations — that become the end product of this identification.

Current physics as we know it only describes objective reality, not the subjective reality of consciousness. The recognition that there is a Causally Active Metaphysical Realism that combines both substance and process is a start in the attempt to give a formal description of what consciousness is, which will lead to an scientific approach to the Hard Problem of Consciousness [16]. This approach will probably result in a new set of scientific laws that extend physics from objective reality alone to encompass both subjective and objective reality. Hopefully, this will culminate in a unification of both subjectivity and objectivity as natural phenomena, as two separate aspects of a physical duality.

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