Article

Complementarity & Reality

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Abstract

Niels Bohr developed the framework of complementarity in response to the binding of measuring device and quantum system into an irreducible whole or "individual" at the instant of measurement. On the grounds that an organism and its environment are also bound irreducibly upon interaction, Bohr extended complementarity to biology and psychology, treating mechanistic reduction of the organism and neural objectification of consciousness as mere perspectives opposed by equally valid perspectives. In contrast to Bohr's aversion to metaphysical speculation, Heisenberg suggested that the quantum-mechanical wave function represents a real entity which determines probable outcomes of measurements given the forces acting on the system. In light of Bohr's parallel between quantum and biological systems, the probability wave of the atom ought to be mirrored in the equally intangible consciousness of the organism. I propose further that life is indeed an irreducible property of the organism and that mechanistic biology mischaracterizes life. Key to my analysis is the dual nature of time.

Keywords: Wave function, quantum measurement, life, species, individual, consciousness.

1. Introduction

According to Niels Bohr, fully describing the interaction of a quantum system and a measuring device requires contradictory classical concepts. Depending on which property of the system is being measured, the relevant concept is either particle or wave. Yet the quantum system itself, as revealed through mathematical analysis, is neither particle nor wave but a superposition of various possible values for each of its variable properties. If we classify the system on its own terms, it seems to occupy an ideal realm removed from actuality. If we classify it in terms that make sense to us – that is, that correspond to sensory existence – we lose its intrinsic nature. For Bohr, complementarity is the closest we can get to a description of a quantum system without sacrificing familiar classical concepts.

Bohr applied the framework of complementarity not only to quantum mechanics but to any relationship in which the subject and object of experimental inquiry cannot be decisively teased apart and therefore must be treated as an individual whole, a novelty in the annals of physics and the reason for the sharp departure of quantum theory from classical theory. Free will and determinism, Bohr suggested, are complementary views onto the human mind. Like the quantum system, which loses its intrinsic nature when measured, the subject of awareness by necessity comes across as an object when placed under examination. In and of itself the conscious agent is

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free, but when we try to bring the self into our empirical grasp, we find only a brain, a tangible object determined by local causal processes. Likewise, the organism may be understood as purposive and irreducibly alive or a bundle of blind mechanisms.

In this article I postulate dual-aspect time so as to arrive, contra Bohr, at a concept of the fundamental reality with respect to both atoms and organisms. My approach to time accords with Heisenberg's conjecture on quantum realism in terms of potentia and event. Whereas an unmeasured quantum system is a function of the fundamental time of *ongoing potentiality*, a measured system belongs to the emergent time of successive events. Only in a succession of distinct moments, each emergent from the fundamental time of the smoothly evolving wave function, do we find the determinate events that provide the building blocks of the sensory world. I propose that life and consciousness express a continuous present of ongoing potentiality while tangible events mark the successive expulsion of completed moments from the underlying temporal continuum. I conclude on this basis that life takes ontological priority over the mechanisms it employs.

2. Bohr vs Everett

Quantum mechanics originated in the study of blackbody radiation, which is emitted by any object that absorbs light at all frequencies and emits color strictly as a product of its temperature rather than material composition (Lockwood 2005, 283). Though classical physics tells us that heat in this case should radiate across a continuum of frequencies, measured outcomes reveal discontinuities. To explain this finding, Planck postulated a minimal unit of action, the quantum of action or quantum jump, as a fundamental constant. Heat radiates at no less than one quantum of energy, which Einstein interpreted as an irreducible unit of light, a photon, in his discussion of the photoelectric effect. The energy of the photon is expressed as Planck's constant multiplied by the light's frequency (Heisenberg 1958, 30-32).

On the basis of this unexpected and purely contingent fact, Bohr postulated that an electron is restricted in its orbit of an atomic nucleus to specific quantized frequencies and therefore never occupies intermediate frequencies but "jumps" discontinuously from one orbital to another. While Bohr was able in this way to account for atomic stability, his quantum postulate posed a serious problem for physics as traditionally practiced (Folse 1985, 63-64).

As with a classical system, fully describing a quantum system requires not only observing it in space-time – that is, interacting with it by way of a measuring apparatus – but defining its state for the purpose of causal analysis and prediction. Inherent to a precise definition of state is the isolation of the system in question. Even in classical physics, measurement slightly perturbs the object under investigation, but this effect is easily calculated and accounted for. Because the quantum of action is "uncontrolled," meaning that it contains a random component, the effect of interacting with the quantum system cannot be subtracted out so as to define its pre-interaction state (Folse 1985, 92-93). Causal analysis, in accord with the conservation laws of momentum and energy, is therefore feasible only in the absence of space-time coordination (Bohr 1958, 19). If we determine where something is, we lose the ability to trace its causal trajectory. This conundrum is commonly expressed in terms of position and momentum. The quantum jump triggered by measurement of the position of a quantum system negates a precise value of its momentum and therefore the causal basis of its position. As Bohr notes, "any observation takes place at the cost of the connection between the past and future course of phenomena" (1987, 11).

Rather than accept that physics had hit a brick wall, Bohr developed a means of preserving the use of intuitive classical concepts even if they fail to describe pre-measurement properties of quantum systems (Folse 1985, 100). Bohr's solution was simply to assume a large-scale classical level of existence in the form of a measuring device and apply classical concepts to the results of measurements in a complementary way. When we measure for position or time, we refer to the result as a particle. When we measure for momentum or energy, the result is called a wave. Particle and wave are of course mutually exclusive; a thing is one or the other, not both. Yet only by successively applying each concept to the quantum system do we get a complete understanding or at least the most complete understanding allowed by nature (1985, 115-117).

The price of complementarity is the abandonment of the correspondence between theoretical representation and reality. This is not to deny objective reality but merely to accept that it fails to conform to concepts developed by humans in the course of evolving in conjunction with large-scale environments (Faye and Folse 2017, 116). Though certainly not a realist, neither was Bohr explicitly anti-realist (Katsumori 2011, 70).

Schrödinger 's wave mechanical formalism of quantum mechanics describes the properties of a quantum system according to an evolving wave function. On this basis Schrödinger proposed that a quantum system is in fact a wave, not a particle. The trouble is that the wave function tends to spread out, whereas particles are always found in narrowly defined locations. Schrödinger's claim was overturned by Max Born, who demonstrated that the wave function discloses the probable outcomes of a measurement (Whitaker 2006, 142, 145-46). Of the many possible values of a physical property encoded in the wave function of a quantum system, a measurement "projects" one of those values into tangible existence. Since the exact measurement outcome is not specified in the probabilistic wave function, projection contains a random component, and only over many measurements are the probabilities verified. After von Neumann, Paul Dirac's projection postulate came to be known as the collapse of the wave function (2006, 195). Since many possible values of a property can exist in superposition in the wave function, the reduction of superposed values into a single definite value indicates a discontinuity in wave evolution, specifically the collapse of the wave function and its reset at a new starting point on the basis of the randomly projected value.

This interpretation of the quantum formalism was dubbed the Copenhagen interpretation in honor of Bohr's quantum research institute. Yet Bohr never used this term and never spoke of wave function collapse (Faye and Folse 2017, 6-7). After all, the collapse of a quantum system from a wavelike superposition of potential states to a single determinate state implies the reality of the former as much as the latter. Whereas Bohr perhaps wisely kept quantum theory as vague and even paradoxical as possible, by giving the theory a definite form Dirac and von Neumann made it a target for attack.

Quantum theory is incompatible with the fundamental aim of classical physics, namely the prediction of behavior on the basis of deterministic law. "The laws of physics," as Sean Carroll explains, "can be thought of as a machine that tells us, given what the world is like right now, what it will evolve into a moment later" (2010, 124). To restore physics to its traditional deterministic orientation, Carroll advocates the "many worlds" interpretation, a natural extension of Everett's relative-state interpretation (2010, 249).

Everett's starting point was the proposal that the Schrödinger equation, the dynamical law from which the wave function is derived, is a complete description of the world (Zeh 2010, 173). In response to Bohr's correspondence principle, according to which the quantum description of a large-scale object must correspond to the classical description, Everett pointed out that the Schrödinger law in no way limits the size of a physical system governed by a wave function (Faye and Folse 2017, 163). No object is beyond its scope. Since collapse is not stipulated in the equation, Everett concluded that the wave function propagates indefinitely without break (Lewis 2016, 20). The ultimate object of quantum mechanics is the eternally propagating wave function of the universe.

If, following Everett, we accept that the wave function describes a real physical state but deny wave function collapse, quantum mechanics is rendered completely deterministic just like classical mechanics. There is a price, however, for maintaining the familiar approach. Because the universal wave function includes a different subset for every possible outcome of a given measurement, every measurable event splits sensorial existence into numerous alternatives, but we experience only the one corresponding to the subset of the wave function we happen to occupy following the measurement (Carroll 2010, 251). The universal wave function is like the trunk of a tree continually sprouting new branches. The world according to one branch is no more real than any other. Though we believe a particular chain of events is taking place, according to Everett the objective state includes additionally every other possible set of events allowed by the wave function. Nothing we experience has any more reality than any other possible experience. Since experience is the basis of empirical investigation, Everett's resolution of a specific problem in physics threatened to derail the entire project of science.

3. The Reality of Potentiality and the Nature of Time

Bohr, as Everett noted, never explained why measurement should produce an irreversible outcome at odds with the time-reversible wave function that describes the quantum system prior to measurement (Faye and Folse 2017, 226). The Schrödinger equation makes no provision for the collapse of the superposed values of a given property into a single definite value. Not only should wave evolution carry on as before, but the interaction of the system with a measuring device ought to incorporate the device into the wave function governing the system. The outcome of measurement should therefore be a superposition of results rather than a single definite result. This is known as the measurement problem (Ney and Albert, 2013, 24).

To understand the collapse of the wave function we must take into account the contingent role of the macroscopic environment in the context of the twofold nature of time. As governed by its wave function, an isolated microphysical system is strictly continuous in its development (Heisenberg 1958, 53). On the basis of the forces acting on the system, which are incorporated into the wave function via the Hamiltonian, each superposition of potential states yields another superposition until environmental conflict, e.g. measurement, forces the system to "choose" one of its potential states to the exclusion of all others. For instance, when an electron collides with a photographic plate, it must leave its mark at a single position, not a superposition.

"Nature," according to Dirac, "makes a choice" (Malin 2001, 127). How else to explain wave function collapse? Not merely measurement devices but any sufficiently intrusive interaction forces a choice upon a quantum system. Moreover, such choices are continually imposed upon the atoms comprising measuring devices. The densely packed atomic constituents of any macroscopic object repeatedly depart from the continuous time of the wave function because their recurring conflicts keep forcing them to jump from a superposition of states to a single actual state at an instant. Only relatively isolated quantum systems enjoy the luxury of uninterrupted wave evolution. As Milic Capek (1971, 198) explains, inherent to microcosmos is microchronos. Unlike the macrochronos of the measuring device, the time of the lone atom need not include discontinuities.

Much of the confusion surrounding quantum theory follows from the status of measurement as a special type of interaction that uniquely translates the microphysical into the domain of experience. In his famous thought experiment involving a cat, Schrödinger begins with a radioactive atom that might or might not emit a photon in a given timeframe. If the photon is emitted, its detection by a gamma ray detector generates an electrical signal which is amplified to the point that it triggers a mechanism that opens a bottle of poison gas. Thus the life of the cat depends on whether or not the atom decays. Since the atom is in a superposition of both emitting and not emitting the photon, the cat – prior to measurement – is in a superposition of both dead and alive (Laloë 2019, 27).

The implication is that a delicate setup is required to scale up from quantum superposition to macroscopic definitude. Yet the cat is made up of atoms undergoing continual interaction, some of which will force each atom to choose among its superposed states, thereby reducing it from its fuzzy wave-mechanical state to a determinate state. If its components remained in a state of superposition, the cat could not exist as such, since no large-scale object bearing definite values of properties can be composed of indefinite atoms. A well-defined house is not composed of fuzzy bricks. The very existence of the cat demonstrates that the transition to definite states at definite moments is always taking place without any measurement process.

That an organism is never both alive and dead means that somewhere between the decay of the radioactive atom and the living being, quantum superposition cuts out. This transition is known as the Heisenberg cut. As Franck Laloë (2019, 26) asks, "when exactly… should this cut be made?" The answer is contained in the question. The cut is defined by the emergence of an *exact* moment from the underlying temporal flux. So long as time is evolving potentiality, the value of a variable property of a quantum system remains indefinite. A given property takes on determinate value when an interaction triggers a definite outcome at a discontinuous moment. When the moment has passed, the system is back to its default state of wave evolution. By this view the classical world of objects with well-defined properties is built up from the cinematic succession of discrete moments.

To overcome Everett's challenge we must accept that reality does not reduce to mathematics but includes contingent facts. As Bohr recognized, far from an intangible quantum system governed by the Schrödinger equation, our starting point must be the reciprocal action of environment and system. Every projection of an atom at an instant from its evolving wave state demonstrates the impact of the classical environment on the atoms comprising it (Drossel and Ellis 2018). As long as densely-packed atoms are repeatedly departing their wave state for classical states, a macroscopic body will reliably collapse the wave function of any stray atom that comes into contact with it.

In contrast to an external interaction that imposes a choice onto a quantum system and thereby forces it to settle, momentarily, on a determinate state, the much-discussed mechanism of decoherence serves only to eliminate interfering terms in the wave function. Though decoherence can generate the appearance of collapse, the collapse postulate, as Laloë points out, is intended to explain not merely a development in the course of wave evolution but its termination in a single measurable outcome. As a mathematical operation "already contained in the Schrödinger equation," decoherence therefore cannot explain the uniqueness of the measurement result. With its assumption that the wave function – an object of mathematics – is the basis of reality, the many worlds interpretation is the natural correlate of decoherence (2019, 211-12).

Bohr seems to have considered mathematical idea the sole alternative to classical reality. Since the wave function in no way conforms to a tangible and three-dimensional classical wave, he viewed it as an abstraction, a mere tool of the intellect (Faye and Folse 2017, 9). Mathematical abstractions are timeless, never tangible yet always applicable. Conditioned by the false dilemma between timelessness and the classical timeline of successive instants, Bohr could not conceive that the succession of wave collapses forming the basis of macrochronos is projected from an underlying temporal continuum. The time of the probability wave, as represented mathematically by the wave function, is neither instantaneous nor abstract but continuous and real. As Laloë puts it, "the wave function evolves gently, in a perfectly predictable and continuous way" (2019, 21).

Had Bohr bothered to comment on Schrödinger's cat, he might have said the cat is never dead and alive at the same time for the simple reason that quantum superposition is not a real physical state (Faye and Folse 2017, 125). But this raises the question of why the wave function, if it has no real-world referent, is such an accurate prediction tool.

We need not accept Everett's belief that the wave function is the whole of reality to recognize that it represents something real. Granted, as Heisenberg points out, "waves in configuration space" lack reality in the sense of an object with definite states in three-dimensional space (1958, 130). Heisenberg also notes that physicists consider the orbit of the electron "not as reality but rather as a kind of 'potentia'" (1958, 181). This dichotomy, however, is misleading. Rather than *contrast* with reality, the potential orbit of the electron merely defines the sort of reality exhibited in wave mechanics. Indeed, Heisenberg speculates that the probability wave is "something standing in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and [tangible] reality."

While potentiality may strike us as less real than actuality, in terms of time the difference is only that between continuity and discontinuity. Why should the instantaneous present have greater claim to reality than the ongoing present from which it emerges? Unlike actual events, potential events need not pass but may remain present indefinitely. If time is real in both the continuous presence of potential events and the discontinuous passage of actual events, the smooth propagation of superposed quantum values encoded in the wave function is as real as the instantaneous atom at a precise location. Likewise, if classical space is real, so is the high-dimensional configuration space that collapses to a mere three dimensions at an instant.

The conventional wisdom of contrasting the continuity of classical physics with the discontinuity inherent to quantum physics reflects a spatial bias pervasive not only among physicists but in human thought generally. In terms of *time*, what is continuous is wave evolution, while the classical reality is founded on the rapid repetition of collapses to determinate states, that is, a succession of instants. Though time is a continuous variable in classical physics, this is a conceptual artifact of the use of calculus, which has no application at very small timescales (Bohm 1951, 148).

Bohr sought to keep scientific explanation within reach of human experience and for this reason confined his analysis to classical concepts such as particle, measurement, space-time, etc. (Faye and Folse 2017, 4). Yet nothing is more immediate than the flux in which all experience is captive. Aside from providing the temporal substrate of wave evolution, ongoing presence is the very definition of consciousness.

4. Complementarity Generalized

Despite the colossal scale of an organism relative to the quantum of action, Bohr maintained that the quandaries long associated with life and mind can be clarified on the basis of complementarity. By generalizing complementarity to encompass biology and psychology, Bohr hoped to provide the basis for "unity of knowledge" or consilience between the natural and human sciences (Bohr 1958, 74).

The quantum jump at the instant of measurement binds system and measuring device into an indivisible whole or *individual*, meaning that the phenomenon arising from the interaction cannot be partitioned into one element corresponding to the measured object and another element – to be subtracted out – that results from the effect of measurement. Every measurable change in the state of an atom, as Bohr noted, is an individual process irreducible to a more detailed description (1987, 108). Bohr's biological interest was not in quantum effects such as superposition or tunneling that might be involved in biochemical processes but the unanalyzable individuality of the living system in conjunction with its environment, paralleling that of the atomic system under measurement. Like the quantum of action from the standpoint of classical physics, life is an "irrational" element of the organism (Folse 1985, 186). Rather than derive the quantum jump from generic principles, Bohr simply recognized it as a fact of nature. Parallel to the quantum postulate is the life postulate (1958, 21).

Just as measurement of position triggers an uncontrolled jump that precludes determining its causal history as expressed in the conservation of momentum and energy, measuring for momentum or energy prevents space-time coordination. Unable to capture the world in a single conceptual system, we must approach our analysis in accord with causality *or* space-time location but not both at once. In his extension of complementarity from physics to biology, Bohr notes that "our desire for an all-embracing way of looking at life" must be balanced with "our power of expressing ourselves in a logically consistent manner" (1958, 80). We can describe the operations of an organism in the language of purpose or that of classical mechanics but cannot mix together the two analyses and remain logical. Likewise, we can apply to consciousness the objective logic of determinism or the subjective logic of choice, but the blending of these descriptions is by necessity incoherent. Life requires a complementary description (Folse 1985, 179).

In the context of a quantum measurement, we may employ the classical concepts of position-instant or momentum-energy but can no longer assume, as in classical physics, that these properties refer to an objective reality apart from our measurements. Likewise, according to Bohr, describing the organism as a set of mechanisms or as an embodiment of an *elan vital* in no way indicates the reality of either an organic machine or a purposive life force. These are creations of our intellect, "phenomena" triggered by observations and interpretations. Though mechanistic and vitalist analyses – like particle and wave – refer to opposed phenomena, each mode of analysis is nonetheless essential for a complete understanding of the organism (Folse 1985, 183-85).

Perhaps in response to the dominant trend in 20th century biology, Bohr emphasized the shortcomings of an exclusive reliance on mechanistic analysis. "If… we speak of a machine as dead," he writes, "this only means that we can give a description, sufficient for our purpose, of its working in terms of the conceptual forms of classical mechanics." Though perfectly suited to a machine, the strictly classical analysis of an organism is incomplete. Moreover, relying solely on mechanistic analysis is impractical since "the interference necessitated by an observation which would be as complete as possible from the point of view of the atomic theory would cause the death of the organism." In the face of metabolism, which requires continual interaction with the environment, we cannot even keep track of which atoms belong to the organism. On the grounds that only an approach based on the complementarity of opposites can explain the workings of life, Bohr placed quantum mechanics *between* classical mechanics and biology (1987, 22-23).

Given the inexhaustible complexity of the organism due to its inseparability from the environment that both shaped it via natural selection and provides the context for its purposive behavior, analysis on the basis of classical mechanics can never provide more than one component of a larger picture. Far from a competing metaphysics of life, the finalistic account discloses the *meaning* of the mechanistic account of a given physiological development or process (Folse 1985, 191-93). Teleological argumentation is legitimate in physiology, writes Bohr, because "it takes due regard to the characteristics of life" (1958, 10).

As a university student the young Bohr saw in Riemann's multivalued functions of a complex variable the perfect analogy for the paradox of objectively describing one's own conscious state.

In complex function theory, due to the infinite values of a complex variable, mapping a function on a single plane generates ambiguity since each point is multivalued. As Henry Folse explains, Riemann proposed mapping functions as "different 'branches' of a single curve, each on a different plane." Thus "each time we orbit a singular point, the value of a function must be represented in another plane" (1985, 175-76). In the same manner, according to Bohr, every self-reflection opens up another plane of objectivity. Every act of introspection, in other words, creates another objective self in place of the subjective self that initiated the introspection. Though the act of willing belongs exclusively to the subject, describing the subject renders it into an object, and no object can act freely but is instead causally determined (1985, 177-78). On this basis Bohr extends complementarity to "the contrast between the feeling of free will, which governs the psychic life, and the apparently uninterrupted casual chain of the accompanying physiological processes" (Katsumori 2011, 21).

Bohr draws a parallel between the act of measurement and the act of introspection, on the one hand, and between the failure of determinism in quantum mechanics and the sense of volition innate to consciousness on the other (1987, 24). Whether we observe a quantum system or reflect on our mental state, the result is a jump to an uncontrolled outcome that precludes classical analysis and demands the complementarity of opposing perspectives. His point is that volition cannot be dismissed on the basis of the familiar determinism of classical physics. By demoting determinism to mere perspective, he grants equal legitimacy to the opposing perspective.

Though generalized complementarity sheds light on life and consciousness, Bohr's discussion suffers from the same shortcoming as his analysis of quantum systems. In each case the framework of complementarity provides no definitive answer but merely pushes the question beyond reach. Are we free or determined? Are we genuinely alive or just machines? To breach Bohr's barrier, we must determine which of the two perspectives defines the fundamental reality and which is subsidiary.

With his claim that thought and feeling are complementary in the same sense as space-time coordination and dynamical conservation laws in quantum theory, Bohr (1958, 52) prepared the ground for a temporal analysis of the mind, though with "feeling" broadened into consciousness, that is, the feeling of being oneself. The line between self-as-subject and self-as-object continually varies because consciousness, like the probability wave, is continuous in time, whereas decisive perceptions and behaviors, like the outcome of measurement, depend on distinct moments apart from the continuous presence that periodically gives rise to them. Consciousness is primarily free insofar as it consists of ongoing potentiality and only secondarily conditioned by physical processes insofar as it consists of a brain with precise properties at well-defined moments. No matter how many objective planes are left in its wake, life itself remains always at the leading edge of time, the ongoing indeterminate present rather than the determinate but fleeting present of the tangible instant. Like the evolving probability wave of the atom, life is an expression of continuous presence but in the context of *self*-nature.

As C.A. Hooker (1989, 243) points out, Bohr connected the quantum of action with the "indissoluble wholeness of composite quantum systems and the physical nature of measurement." Yet irreducible wholeness is already evident, outside of the measuring process, in the multi-particle system under the direction of a single probability wave. As Bohr himself noted, no photon exists in an atom between its absorption and emission, meaning the atom cannot be broken down into parts but is defined at the level of the whole (Capek 1991, 202). This deeper form of holism sets the stage for biological individuality. The quantum individual, Bohr's instantaneous union of system and environment, is strictly a function of moment-to-moment successive wave collapses. But the living individual, in addition to being bound to the environment upon each moment of interaction, maintains itself over time *apart* from its environment. As revealed by the enduring self-identification of the organism, life is a reinstatement of continuous time at the classical level.

Even the humble atom is beyond the reach of classical analysis. Like an organism – and in contrast to, say, a solar system – an atom returns to its original state after being disturbed (Bohr 1958, 17). Though Bohr goes no further with his analogy between atom and organism, on the basis of temporal metaphysics we may venture onward.

In the course of environmental conflicts, each of which forces a choice among superposed possibilities, an atom is repeatedly reborn as a material individual in a precisely defined state. Likewise, the birth of a biological individual indicates the projection from the many potential states of its species to a particular state as implemented by the random combination of genes from each parent. Though initially defined by a set of tangible traits, each of us gradually takes on the capacity for conscious self-determination, that is, ongoing self-creation. A machine, on the other hand, has no relationship to the time of ongoing potentiality beyond its microphysical components.

Rather than regard mechanisms and purposes merely as alternative ways of characterizing organic activity, as Bohr would have it, mechanisms are the tools utilized by the organism to satisfy its goals. So long as vitalism is simply the recognition that life is irreducible to classical physics — as opposed to the claim that a non-physical force animates living tissue – it provides an essential jumping off point for biological investigation.

Wave function realism means that an atom free of environmental interaction has no definite values of its variable properties but consists instead of the continuous propagation or *computation* of potential values in superposition. Rather than locatable in or near the atom, probabilistic computation *is* the isolated atom. What, then, does wave-mechanical realism imply for life and mind? The immediate implication is that the mind is irreducible to the body in exactly the sense that the probability wave is irreducible to the atom. Like the computation of possible outcomes of looming atomic interactions, the mind is the computation of possible outcomes of looming social or environmental interactions. Moreover, mind is implicit in not only the consciousness of the individual but more fundamentally the emergence of the organism from its species, i.e. birth. An individual mind is only the surface of an oceanic body of computation commonly referred to as a species of life. Far from merely an abstract universal, a biological species is a *living* universal that periodically outputs living individuals.

5. Conclusion

Hooker (1989, 246) observes that no "satisfying metaphysics" has been put forth to provide a basis for Bohr's framework of complementarity. "Bohr describes quantum theory as a 'rational generalization' of classical physics. This it may be, but he is unable to explain why it is this particular rational generalization which applies in our world and not some other" (1989, 243). The answer lies in the nature of time. The complementarity of wave and particle expresses the duality of continuous and discontinuous time. Unlike Bohr's framework, temporal metaphysics lends itself naturally to ontological ordering. As the classical world emerges moment to moment from the fundamental time implicit in the smoothly evolving probability wave, organisms emerge generation to generation from the ongoing potentiality of their species.

Explaining both the quantum postulate and the life postulate requires a time postulate: the fundamental reality is the indeterminate flux of ongoing presence, that is, *now* without end. Whereas a quantum system in isolation is free to propagate superpositions of potential values of properties, choice-forcing conflict between neighboring systems requires definite outcomes at definite, if fleeting, moments. Though emergent and approximate, the classical world is no less real, for otherwise the environment could not trigger wave function collapse. That all cats and all measuring devices merely approximate the fundamental reality in no way denies them their power to collapse probability waves. Like gravity moving matter and matter curving space-time in general relativity, the effect of the wave-mechanical and the classical is reciprocal.

This is not to justify, however, Heisenberg and C.F. von Weizsäcker in their application of complementarity to classical and quantum mechanics themselves. Von Weizsäcker derived his "circular" complementarity from the observation that the wave-mechanical description of nature presupposes the classical space-time concepts that connect it to experience, while the classical description is in turn influenced by the findings of quantum mechanics (Katsumori 2011, 41-42). The circle is broken, however, with respect to the nature of time. Whereas the discrete instant emerges from the background flux, the fundamental continuity of time not only has no need of the instant but manifests at the classical level as momentum, energy flow, causation, life and consciousness. Bohr was right to restrict complementarity to the phenomenal domain. When it comes to the metaphysical distinction between what is primary and all-pervasive and what is secondary and restricted, Bohr's framework has no application.

Sean Carroll's preferred alternative to complementarity is Everett's universal wave function continually multiplying the number of worlds encoded within it. When neighboring atoms are both likely to occupy the same location, instead of a decisive resolution at a precise moment in which only one of the atoms takes the preferred location – that is, a tangible *event* – the universal wave function simply branches to accommodate both possible resolutions. Nothing definitive ever takes place.

Instead of Carroll's eternally branching utopia – a "no place" insofar as it never *happens* – we have a complementarity that is generalized and transcended. First, it extends both to biology – with species in the role of probability wave and individual in place of tangible atom – and to psychology, wherein probabilistic computation manifests as reflection and deliberation while the determinate element consists of judgment and behavior. Second, Bohr's framework is transcended altogether insofar as the ongoing presence disclosed by the probability wave is fundamental whereas its successive projections as fleeting events are subsidiary. Far from merely complementary viewpoints, continuous presence and discontinuous passage constitute the underlying reality and its emergent approximation.

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