

WHITEHEADIAN PHYSICS:
A SCIENTIFIC AND PHILOSOPHICAL ALTERNATIVE
TO CONVENTIONAL THEORIES

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CHAPTER 3

Bridging Necessity and Contingency in Quantum Mechanics:
The Scientific Rehabilitation of Process Metaphysics

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PART I

First Principles and Modern Science:
On Description and Explanation in Quantum Theory

You cannot go on ‘explaining away’ for ever: You will find that you have explained explanation itself away. You cannot go on ‘seeing through’ things for ever. The whole point of seeing through something is to see something through it. It is good that the window should be transparent, because the street or garden beyond it is opaque. How if you saw through the garden too? It is no use trying to ‘see through’ first principles. If you see through everything, then everything is transparent. But a wholly transparent world is an invisible world. To ‘see through’ all things is the same as not to see.¹

-- C.S. Lewis

Can the scientific study of a contingent and mutable world ever, by itself, lead us to the necessary and immutable principles underlying its essence and origin? Can a ‘true and complete’ scientific explanation of the world’s most fundamental features contain anything less than these fundamentally necessary and immutable principles? In most cases, we are well satisfied with the ‘true yet incomplete’ theories yielded by the scientific method. But when ‘fundamental’ scientific theories such as quantum mechanics or string theory are applied to ‘fundamental’ ontological and cosmogonic questions, the ‘true yet incomplete’ theories typically fail to hold sway. Even despite any associated empirical validation, it is difficult to see how an incomplete fundamental theory—i.e., one which presupposes any of its features—could be accepted as the ‘true explanation.’ Whatever comfort we take in the ‘true but incomplete’ explanations science provides in answer to the non-fundamental questions—the evolution of species, for example—that comfort is ultimately grounded in the belief that there is some wider and deeper (and most important, compatible) truth underlying such explanations. But with the fundamental ontological and cosmogonic questions attended to by theories such as quantum mechanics, big bang cosmology, and string theory, that deeper, most fundamental truth is the very truth aimed at in the first place.

Although these particular theories do not provide complete answers to the questions to which they attend, one ought not conclude that the value and certainty of the knowledge they provide are therefore vitiated; though these theories ultimately do little to ‘explain’ the universe in the sense of accounting for its features without recourse to un-falsifiable presuppositions (i.e., physical-philosophical ‘first principles’), they describe certain of its features quite well. We do well, then, to consider the relationship between scientific description and explanation of phenomena—first by avoiding the typical conflation of these two concepts, and second by considering what distinguishes them and whether their separation can be bridged—whether and how the elevation of scientific description to fundamental explanation can be achieved by the scientific method alone.

It is an epistemological question given early and thorough treatment by Plato in the *Theaetetus*, and even though his work long predates the hypothetico-deductive method of modern science, the two primary fuels of this method—inductive and deductive reasoning, were well

¹ C.S. Lewis, *The Abolition of Man or Reflections on Education with Special Reference to the Teaching of English in the Upper Forms of Schools* (Macmillan, 1947), 91.

considered by Plato and remain crucial to the question considered here. Though Plato believed there to be a wide and deep chasm--χωρισμος--separating contingent phenomena and the necessary principles underlying them, a separation of what appears to be from what is reasoned to be, Plato nevertheless believed there to be connections spanning this gulf. In the *Parmenides* (132d1) he considered two types. The first of these is μεθεξις, or ‘participation’ of the immutable principles in mutable phenomena--perhaps in the sense of the governance of the latter by the former. One could argue that it was Aristotle’s overemphasis of μεθεξις that led to the well-known failures of his physics. For Whitehead, by contrast, μεθεξις is a more subtle governance, but no less fundamental to the phenomena governed. He writes, “The metaphysical first principles can never fail of exemplification. We never catch the actual world taking a holiday from their sway.”² The second type of Platonic bridge between description and explanation is μιμησις, or the ‘duplication’ of these principles in the phenomena observed. Certain ontological interpretations of quantum mechanics, as will be discussed presently, make thorough use of both types of connection, either implicitly, or when correlated with Whiteheadian metaphysics, explicitly.

For now, though, let us propose simply that the elevation of scientific description to explanation typically depends upon two desiderata: 1) the greatest possible scope and reductive depth of description, given that the more fundamental the description, the more universal it is considered to be; 2) the least number of presupposed principles required by the theory—i.e., those principles incapable of invalidation by the scientific method. When Steven Weinberg proclaimed that string theory was more philosophy than science, given its manifold un-falsifiable presuppositions, it was the latter desideratum to which he referred. Also implicit in his statement was the notion that philosophical explanations, given their reliance on presupposed principles, are therefore less valuable than scientific explanations. Nevertheless, because of the impressive scope of string theory’s fundamental description of the universe (in accord with the first desideratum above), Weinberg remains one of its best known advocates.

In the *Theaetetus*, Plato quickly dispenses with this first desideratum—the scope and reductive depth of description as a sturdy bridge across the chasm to explanation. In the dialogue, Socrates tells Theaetetus of a dream he once had wherein he had learned of a theory of explanation by which all things are described as complexes of simpler elements, themselves complexes of still simpler elements. This reduction continues until the simplest elements are apprehended, at which point a complete and true explanation of the initial object is achieved. It is only then, proposes Socrates, that one can be said to possess true knowledge—i.e., explanation—of the object. Theaetetus eagerly accepts this epistemology, but Socrates advises caution; he explains that in his dream, the most fundamental elements are incapable of description by this epistemology, given that they contain no simpler parts. Therefore, the most fundamental elements are immutable, perfect, necessary, and unfortunately, unknowable. How, asks Socrates, can the unknowable be the foundation and ultimate justification of knowledge? Plato’s χωρισμος is not so easily bridged, and this is the ultimate thesis of the *Theaetetus*.

The second of the two desiderata for the elevation of scientific, reductive description to explanation—the least possible number of presupposed first principles—clearly follows from this Platonic critique of materialist-reductionist epistemology. For if the most fundamental constituents of our world are ultimate principles rather than ultimately simple material elements, then we *can* know them, since we can arrive at these by reason alone—perhaps inspired by scientific reduction, but not justified by science alone; as Plato demonstrates quite well, attempts at such justification cannot yield fundamental explanation, but merely descriptive knowledge

² Alfred North Whitehead. *Process and Reality: An Essay in Cosmology, Corrected Edition* D. Griffin, D. Sherburne, ed. New York (Free Press, 1978), 4.

which, since it is based on fundamentally unknowable constituents, is knowledge that cannot live up to the true meaning of the word—especially when science seeks to provide knowledge in answer to the ultimate questions, ontological and cosmological. Nevertheless, deductive reasoning is, in its own way, as reductive as the materialistic reductionism Plato criticizes; first principles cannot be avoided because they cannot be deduced from any more fundamental principle. But they can at least be known by hypothesis, as Whitehead advocates via his conception of ‘speculative metaphysics.’ For Whitehead, as for Plato, erroneous knowledge is a kind of knowledge nevertheless, as is, of course, the correction of erroneous knowledge. Regardless, the presupposition of first principles cannot be avoided, whether inquiry be philosophical or scientific. Even when it comes to the fundamental principles of logic operative in mathematics, these principles cannot be accounted for by mathematics alone, as Gödel demonstrated with his Incompleteness Theorem. Russell and Whitehead earlier explored similar issues with respect to set theory in *Principia Mathematica*.

The Platonic chasm between the description and explanation of phenomena—the wide gulf separating what appears to be from what is reasoned to be—is not easily traversed. The scientific method alone cannot bridge this expanse. The infamous Problem of Measurement in quantum mechanics is, perhaps, the best modern exemplification of the difficulty as it entails the presupposition and correlation of 1) mathematical and philosophical first principles, and 2) fundamental, ultra-reductive physical descriptions of phenomena. Evocative of Socrates’ dream in the *Theaetetus*, quantum mechanics describes objects most fundamentally as complex systems of irreducible entities, wherein the ‘state’ of such a system entails a maximal specification of these entities. Quantum states evolve as discrete events, just as their constituent entities do. Most important, however, the theory does not allow for the qualification of these entities ‘in between’ their quantum actualizations, and it is at this point that the epistemic reduction suggested by Socrates meets its end with the ‘unknowable.’ In other words, the potential entities out of which the actual quantum entities evolve are indescribable, at least by way of some more fundamental physical entity.

What ‘really exists’ in between quantum actualizations cannot be described—at least by the same epistemology we use to describe the actualities that evolve from them. One is reminded here of Hume’s rhetorical questioning of our existence in between moments of perception. Indeed, most people intuitively believe in their ‘evolution’ from moment to moment, from experience to experience. We are obviously not the same people we were a year ago, or a day ago, or a minute ago. And yet we also believe in our enduring identities which somehow exist in between these quantum experiences, bridging them and even affecting them. Some interpretations of quantum mechanics have proposed like-minded bridges between quantum actualizations; some maintain that quantum actualities remain actual throughout their evolution, and that the ‘unknowable’ intervals of evolution derive from nothing more than an experimental epistemic limitation, easily attended to by statistical mechanics. Though the inequality of statistical and quantum mechanics would ultimately be demonstrated experimentally, the desire to further reduce quantum mechanical evolutions to fundamental actualities would persist—an allegiance to the first principle of Empedocles, that no thing can arise from nothing—that all real things are actual things. As pervasive and persuasive as this first principle has been for modern science, attempts to reconcile it with quantum mechanics would result in an even more profound difficulty:

The evolution of a quantum mechanical state is described by a wave function, and as this wave function describes entities that are not yet actual, it is never observed experimentally. (In any case, one wonders how one could ever observe an evolution apart from its associated initial and final actual states.) Since it is via the wave function that we are able to calculate the probabilities of various potential actualizations terminal of the evolution, and since these probabilities produce interference effects that influence their potential actualizations, it is difficult to avoid assigning at least some ontological significance to the wave function and its associated

potentia. Certain interpretations of quantum mechanics do so by treating the superposition of co-existent potentia in the wave function as a superposition of co-existent, alternative actualities. Since such superpositions are never observed experimentally, one wonders 1) why this is so, and 2) where these alternative actualities are. Perhaps the most famous answer to these questions was given by Hugh Everett in his Relative State interpretation of quantum mechanics, wherein every potential actuality is actualized in its own relative actual universe.³ Here, the principle of many universes derives from the presupposed first principle of Empedocles—that all real things are actual things—a first principle that quantum mechanics has made, at least in this case, unbelievably expensive.

Even for those theorists who are willing to part with Empedocles and believe that potential actualities are ontologically significant—i.e., *real* despite being non-actual, quantum mechanics poses yet another difficulty: The formalism does not provide any mechanism for actualization—that is, for the production of observable actuality. Here the Platonic chasm looms so large that science can no longer ignore it: On one side lies what *appears to be*—i.e., the physical descriptions, both classical and quantum mechanical, of observed actual phenomena—the initial and final states of the evolution; and on the other side lies what is *reasoned to be*—i.e., the mathematical formalism of the wave function and its evolution from probabilities to actuality. There is, in other words, no physical or mathematical causal connection between observable actual events and the quantum mechanical mechanism for their creation and evolution. This question of how a mathematical superposition of manifold possibilities can evolve to become a particular observable actuality is the infamous Problem of Measurement in quantum mechanics.

Where Everett attempted to bridge this chasm by hypothesizing a principle of parallel universes, other theorists such as Philip Pearle, with later work by GianCarlo Ghirardi, Alberto Rimini, and Tulio Weber⁴, have sought out an actual, dynamical, physical process which collapses or ‘localizes’ the manifold potentia of the wave function into a unique actual outcome. Their ‘spontaneous localization’ interpretation is an effort to ‘complete’ quantum mechanics evocative of Socrates’ proposal, in the *Theaetetus*, that a true explanation is the product of a complete, reductive description. But it is difficult to see how the spontaneous localization interpretation, or any interpretation that seeks out a more fundamental actuality to explain the actualities yielded by quantum mechanics, can avoid the same roadblock Socrates described to Theaetetus. Again, the first principle of Empedocles—that all real things are actual things—extracts a high price when imposed upon quantum mechanics.

But what if an alternative first principle were embraced instead—one no less reasonable than that of Empedocles, but one that could resolve the Problem of Measurement, as well as the other conceptual difficulties of quantum mechanics? Against Empedocles, Aristotle held that potentia and actuality are two species of reality—and further, that actualities give rise to potentia, which give rise to actualities. Heisenberg saw the value of grounding quantum mechanics in this Aristotelian first principle, for the concept of co-existent potentia is no problem at all, nor is the notion that potential outcomes can interfere with one another and influence actual outcomes. But as to the mechanism governing the evolution of manifold potentia to single outcome, Aristotle’s subordinate principle of final causality—that these evolutions are ‘pulled along’ by the evolving actuality’s natural end rather than ‘pushed along’ by external efficient causality—would be less than desirable, especially since it was this emphasis on final causality that led to the failure of Aristotle’s own physical theories.

Physicist Roland Omnès, however, has argued that the ‘mechanism’ governing the evolution of potentia to actuality is really no mechanism at all, but merely the necessary

³ Hugh Everett. “‘Relative State’ Formulation of Quantum Mechanics.” *Rev. Mod. Phys.* 29 (1957): 454-462

⁴ Ghirardi, G. C., Rimini, A., Weber, T.: “Unified dynamics for microscopic and macroscopic systems”, *Phys. Rev. D* 34 (1986): 470-491

satisfaction of two simple first principles of logic—principles so fundamental that until today they have been largely overlooked by science, even though the universe would be utterly inaccessible to the scientific method it ever “took a holiday from their sway,” as Whitehead would say. These are the Principle of Non-Contradiction (PNC) and the Principle of the Excluded Middle (PEM). The Principle of Non-Contradiction (a key Aristotelian first principle) as applied to the quantum mechanical evolution of potentia to actuality simply holds that given a potential fact and its negation, p and $\sim p$, *at most* one will be actualized. The Principle of the Excluded Middle holds that *at least* one will be actualized. By PNC, macroscopic superpositions of alternative actualities can never be yielded by quantum mechanics; and by PEM, *some* actual outcome is guaranteed. Together, PNC and PEM guarantee that for any pair of potential alternative outcomes, one will become actual. And since actualities are both the beginning and the end of a quantum mechanical state evolution, one can simply envision objects as serial historical routes of actualized quantum mechanical states in a perpetual state of evolution, from actuality, through potentiality, to actuality.

These principles are not merely philosophically significant, however; they are crucially operative in the mathematical formalism itself, particularly as regards the concept of state reduction—a quantum mechanical innovation as infamously problematic as the problem of measurement discussed earlier. The wave function descriptive of a state’s evolution initially contains far more potential outcomes than the reduced set of probability-valuated outcomes terminal of the evolution. The question of ‘what drives state reduction’ or ‘what drives the elimination of so many potential outcome states’ is easily answered by way of PNC, so long as it is explicitly acknowledged that quantum mechanics describes the evolution of systems of actualities (again, the ‘state’ of a system is a maximal specification of its constituent actualities.) Since the state of a system changes when even one of its constituent actualities changes, the potentia associated with each evolving actuality are entangled, even when spatially well separated. The larger the system, the more complex the entanglement. By PNC, entanglements that result in logically incompatible potential outcomes are eliminated, and the manifold potential outcomes associated with a system are reduced to a set of mutually exclusive and exhaustive outcomes. And by PEM, one of these outcomes is guaranteed, which makes these potentia valuated *probabilities* in that together they sum to unity.

Interpretations of quantum mechanics that explicitly make use of PNC and PEM in this way are those that make use of the ‘decoherence effect,’ which refers to the mathematical cancellation of interfering entangled potentia and the evolution of these potentia to a reduced set of probability valuated, mutually exclusive and exhaustive outcomes. Since the decoherence effect requires systems with many degrees of freedom to effect the necessary cancellations, interpretations that make use of the decoherence effect always rely on the complex coupling of a measured system with its environment. While other interpretations ignore the environment and idealize the measured system as an ‘isolated’ system, it is always understood that divisions of system and environment are purely arbitrary. Even many of the quantum theory’s earliest contributors, among them Heisenberg and von Neumann, maintained that when a measured system evolves quantum mechanically, so must the measuring apparatus and the environment englobing both if quantum mechanics is to be considered a truly universal theory. Even if quantum mechanical treatment of the environment and measuring apparatus is avoided in practice since it would make calculation impossible, recent theorists advocating the decoherence effect argue that it is these traditionally ignored aspects of quantum mechanical measurement that, when governed by PNC and PEM (in the same way that every other object of scientific inquiry is governed), hold the key to resolving some of the quantum theory’s most vexing conceptual difficulties.

Though there are a great many benefits to the ontological interpretation of quantum mechanics presented thus far, there are two which stand out: First, this interpretation is a truly universal interpretation of quantum mechanics. Unlike models based upon Bohr’s notion of

complementarity with its arbitrary divisions of the world into ‘subject’ and ‘object,’ each with its own exclusive epistemic framework, the decoherence-based interpretations require no such division; rather, these interpretations make use of the principle that facts and histories of facts belonging to ‘subject,’ ‘object,’ and ‘environment’ are necessarily ontologically interrelated. These interrelations give rise, via the Schrödinger equation, to manifold integrations of potential outcome states which, via nothing other than the process of logical integration itself, eliminates superpositions of interfering potential outcome states incompatible for integration. The decoherence-based interpretations thereby purge quantum mechanics of its infamous predication of objective reality upon subjective--and by some interpretations, necessarily human--observations. It is because of this first benefit that decoherence-based interpretations of quantum mechanics are often described as ‘quantum mechanics without observers.’ Of course, this characterization isn’t entirely accurate insofar as ‘observation’ by this interpretation is described as the interrelation among all facts subsumed by a system--i.e., observer-facts interrelated with measured system-facts and environmental facts. The advantage of the decoherence-based interpretations is that they explicitly acknowledge and make use of the concept that the universe itself is the only truly closed system, and therefore *all* facts englobed by this system are necessarily mutually interrelated and ontologically incapable of isolation; and by this principle, the role of the ‘observer’ in orthodox quantum mechanics is always fulfilled.

In fact, it has been suggested by Gell-Mann and Hartle that the mostly-classical or ‘quasiclassical’ behavior of the relatively high-inertia macroscopic objects we typically encounter in everyday experience is, in part, a product of the decoherence effect; but it is also a product of the extremely high degree of historical correlation among facts--i.e., reproduction from fact to fact along an historical route--typical of high-inertia systems, such that it is always potentia with probability valuations extremely close to one which are reproduced with great regularity along a given historical route of facts. This tendency toward potentia regulated by reproduction is typical of the high-inertia systems which constitute most of our everyday world. Schrödinger’s Cat, for example, is a sufficiently large enough system of facts that its own high-inertia ‘internal environment’--apart from the unavoidable coupling with the environment ‘external’ to the cat (the air it breathes interacting with the box it is in, interacting with the world outside the box, etc.)--easily provides the requisite degrees of freedom to produce the necessary cancellations of interfering potential states; and those potential states which survive the cancellations are highly regulated by closely correlated reproductions among facts constituting the historical route of the cat. The result is that if the cat is dead at time t , there is a probability extremely close to one that it will be dead at time $t + 1$ as well. These two factors combined--decoherence, and highly regulated reproduction among facts comprising high-inertia systems--offer a clear ontological account as to why we never see live-dead cat superpositions, or any other macroscopic superpositions even though such superpositions are a necessary conceptual component of quantum mechanics. Bluntly stated by Gell-Mann: “Reams of paper have been wasted on the supposedly weird quantum-mechanical state of the cat, both dead and alive at the same time. No real quasiclassical object can exhibit such behavior because interaction with the rest of the universe will lead to decoherence of the alternatives.”⁵

The second benefit of this conception of system states as histories of actualities/events/facts is that it allows one to intuitively see how the so-called ‘problem’ of quantum nonlocality--arguably the most formidable obstacle to a strictly classical accommodation of quantum mechanics--is really no problem at all. Quantum nonlocality is simply the correlation among facts in a composite quantum system, when *system*, *detector*, and *environment* entail actualities which are space-like separated. For according to the formalism above, facts belonging

⁵ Murray Gell-Mann. *The Quark and the Jaguar: Adventures in the Simple and the Complex*. New York (W.H. Freeman and Company, 1994), 153.

to the experimental environment, even though they may pertain to a part of the universe far removed from the system measured and the measuring apparatus, nevertheless affect the actualization of potential facts belonging to the system and the apparatus.

The problem of quantum nonlocality was first formally addressed in the famous paper of Einstein, Podolsky and Rosen (EPR) in 1935, and in 1969 an experiment was designed by Abner Shimony, John Clauser, M. Horne, and R. Holt which would test the EPR argument and its newer formulation by David Bohm--that supposedly non-local correlations are merely statistical artifacts which derive from hidden variables, and that if these variables were disclosed, quantum mechanics would be a complete, fully deterministic theory. In 1964, John Bell demonstrated mathematically that the non-local correlations predicted by quantum mechanics exceeded those predicted by classical, statistical mechanics⁶; his theorem was tested experimentally in 1972 by Clauser and S. Freedman,⁷ and in 1982 another version of the experiment was performed by A. Aspect, J. Dalibard, and G. Roger.⁸ The results of these experiments vindicated quantum mechanics by their demonstration of non-local interrelations in excess of those allowed for by classical statistical mechanics--to the surprise of many. In the years since these experiments, a great deal has been written about this supposedly bizarre, counterintuitive, and conceptually problematic non-locality feature of quantum mechanics.

The interpretive strategy represented by the arguments of Einstein, Podolsky, Rosen, and Bohm entails the characterization of quantum nonlocality--as well as indefiniteness, chance, entanglement, probability--as epistemic artifacts of the quantum theory's inability to account for a multiplicity of 'hidden variables' which, if disclosed, would complete the theory. Thus, quantum mechanics would be cleansed of all uncertainty so that its true essence as a fully determinate, classical theory would be revealed. Since human limitations prevent the specification of these deterministic hidden variables, however, the incompleteness of the theory with its unmovable veil of indeterminism relegating us to a statistical approximation of them. Thus the matrix of probable outcome states yielded by quantum mechanics is to be interpreted, as advocated early on by Max Born, as statistical probabilities of purely epistemic significance⁹--probabilities that describe the statistical frequency at which an experimenter measuring the position of an electron, for example, finds it in a given region around an atomic nucleus after repeated experiments--i.e., the probability that one will find that the *pre-established facts* will fit a *probable form* a certain percentage of the time when a given experiment is repeated sufficiently.

This statistical interpretation of quantum mechanics is thus able to account for indefiniteness, change, probability, and entanglement by rendering these concepts merely epistemically significant, as opposed to ontologically significant. But the statistical or 'hidden variables' interpretation of quantum mechanics is not so easily able to account for nonlocality; for even if non-local correlations between spatially well separated systems are interpreted as statistical artifacts owing to hidden variables--which, for example, might pertain to stochastic fluctuations within the field of atomic and subatomic particles linking the two systems--the classical interactions among these particles are still limited by the speed of light boundary of special relativity. Any causally significant transference of energy from one system to the other along the field--whether statistically veiled by its (apparently) stochastic fluctuations, or whether explicitly apparent as in a communication signal beamed from one system to the other--cannot

⁶ John Bell, "On the Einstein Podolsky Rosen Paradox," *Physics*, 1,3 (1964), 195-200.

⁷ S. Freedman and J. Clauser, *Phys. Rev. Lett.* 28, (1972): 934-941.

⁸ A. Aspect, J. Dalibard and G. Roger, *Phys. Rev. Lett* 44, (1982):1804-1807

⁹ Max Born, "Bemerkungen zur statistischen Deutung der Quantenmechanik" in *Werner Heisenberg und die Physik unserer Zeit*, F. Bopp ed. (Braunschweig: F. Vieweg, 1961), 103-118

exceed the speed of light. But the experiments of Aspect, *et al*, reveal that if nonlocality is to be explained according to this classical deterministic model, these propagations along the field must be superluminal.

In answer to this difficulty, many advocates of the experimentally disconfirmed classical, 'local hidden variables' interpretation moved to embrace a 'non-local hidden variables' interpretation, which is otherwise the same in its classical interpretation of quantum mechanics--except that it allows for non-local interactions via a superluminal propagation of energy, in violation of special relativity. The non-local hidden variables theory of David Bohm, introduced in 1952,¹⁰ is the most complete and systematized incarnation of this type of theory; in it, Bohm suggests that the entire universe is permeated by a field of point particles whose interactions can be described and accounted for via quantum mechanics. This not only allows for non-local interactions via superluminally propagated energy, characterized as a kind of 'shock wave,' similar to the 'pilot wave' model proposed by de Broglie in 1927; it also renders the universe fundamentally time-reversal invariant--i.e., purely deterministic, such that past, present, and future are all mutually internally related.

This is, it would seem, a serious price to pay--the salvaging of fundamental classicality by means of selected violations of its most core principles, not the least of which being the speed of light limit given by special relativity. And yet quantum nonlocality, when interpreted via a satisfactory ontological framework such as that proposed by Omnès, Gell-Mann, *et. al.*, is entirely reasonable and intuitive--so much so, in fact, that one can use 'real world' situations to demonstrate this interpretation of quantum nonlocality (a good indicator of the coherence of this ontological framework). The following quantum non-locality analogy is an example of what is sometimes referred to as a 'Cambridge Change'--a term which likely derives from P.T. Geach's use of it in his 1969 book *God and the Soul*.¹¹ The term refers to Cambridge philosophers such as Bertrand Russell, who had considered the idea of changing descriptive qualifications (e.g., per this discussion, 'changing quantum mechanical states') as ontologically significant to the object of the description. Thus, as an historical route of quantum mechanical state specifications changes with each quantum augmentation of the history, the system of actualities described by (or better, constituted by) the historical series also changes in some sense.

Consider, for example, the history of actualities/events/facts comprised by a traveling salesman, whose pregnant wife in California is soon to deliver. Certain of the actualities/events/facts belonging to the salesman pertain to his location, which is somewhere in Hong Kong, far away from his wife. Nevertheless, the history describing the salesman is correlated with the history describing his wife, such that as soon as she gives birth, we can say that the salesman's history has been augmented in a definite, objective way, evinced by asking the simple question: When does the salesman become a father? When, in other words, are the potentia *objectively pertinent* to his state affected? According to a classical mechanical interpretation of this situation, the answer would be: As soon as his wife is able to communicate this fact to him--communication limited to the speed of light, according to special relativity.

But according to a quantum mechanical interpretation of this situation, the history of states describing the salesman instantly changes as soon as his wife gives birth, by virtue of the fact that his state history is correlated with that of his wife; the correlations of their two histories are accounted for by two concepts: (i) Both histories are correlated with an environmental history,

which is itself englobed by the universal history $|\Psi\rangle$, and therefore all these correlated histories must be mutually logically consistent; (ii) the consistency among the salesman and wife histories

¹⁰ David Bohm, *Phys Rev.* 85 (1952): 166,180. See also: David Bohm, B.J. Hiley, *The Undivided Universe: An Ontological Interpretation of Quantum Theory* (London: Routledge, 1993)

¹¹ P.T. Geach, *God and the Soul*, London: Routledge, (1969) 71-72.

is, at least in part, a function of the decoherence effect, which eliminates any logically incompatible, interfering histories in the pure state density matrix, such that the alternative histories comprising the reduced state density matrix are logically consistent, mutually exclusive and exhaustive probabilities.

The fact that the history of states describing the salesman changes as soon as his wife gives birth does not, as has been suggested in some discussions of the real experiments involving quantum nonlocality, imply any ‘superluminal communication’ in violation of special relativity. Theoretical exploration of the possibility of such faster-than-light communication via quantum nonlocality has revealed that correlations among non-local histories cannot involve the communication of information. Put another way, quantum mechanics allows the actualities of one system to causally *affect* the *potentia* of a spatially well-separated system by virtue of the correlated histories of the two systems; quantum mechanics does *not*, however, allow spatially well-separated systems to causally *influence* one another. This distinction between *causal affection of potentia by logically prior actuality* and *causal influence of actualization by temporally prior actuality* is perhaps negligible in classical mechanics, where both constitute the qualification of material substance by quality. In an ontological interpretation of quantum mechanics, however, the distinction between *causal affection of potentia* and *causal influence of actualization* is directly related to and necessitated by the ontological significance of potentiality. For as the evolution of a state or history of a system is driven by the potentia associated with the system--potentia which are subsequently and consequently related to all logically prior facts in the closed system of the universe--an *affection* upon these potentia does not necessarily entail causal *influence* upon the quantum mechanical actualization of the system.

The state history of the salesman, in other words, involves not only the actualities/events/facts subsumed by his state history as it *exists*, but also the *potential* actualities/events/facts subsumed by state history as it *evolves*; and it is these potentia which are affected non-locally. Though he is not aware of his state change, for the same reason superluminal communication is not possible in quantum mechanics, the potentia associated with the salesman’s *subsequent* and *consequent* history--and the role of these potentia in forming the probabilities for their actualization--is affected, and in an ontologically significant way.

This rather abstract example is, of course, not offered as a precise comparison with or exemplification of the EPR-type ‘nonlocal’ phenomena yielded by experiment. But while it is obvious that a human being is not usefully *equated* with a subatomic particle, such particles are nevertheless fundamental to the description of a human being as a physical body. As such, the latter can be reasonably described (though not exhaustively, of course) as a quantum mechanical system of facts *such that the relations among these facts at the microphysical level might reasonably find their reflection at the macrophysical level*. The benefit of rendering explicit this implicit understanding of ‘classical’ bodies as quantum mechanical systems of facts, as von Neumann argued, is that brings both ‘observer’ and ‘observed’ into the formalism, recasting the latter into a more fundamentally coherent physical theory. In that sense, one can very reasonably suppose that the intuitive ontological concepts discussed in these abstract, ‘classical’ examples of ‘nonlocality’ are at least *somehow* reflective of those used in interpreting nonlocal quantum phenomena in the famous EPR-type laboratory experiments performed by Aspect, Dalibard, *et al.* This might be taken as an important indicator of the coherence of this ontological interpretation of quantum mechanics.

Those interpretations of quantum mechanics that make use of the decoherence effect—among them, those proposed by Omnès, Griffiths’ Consistent Histories interpretation, Gell-Mann and Hartle’s decoherent histories approach, Wojciech Żurek’s Environmental Superselection interpretation—are unique in their reliance upon the explicit operation of two categories of first principles, ontological and logical. The ontological first principle is that which categorizes actuality and potentiality as two species of reality—a long overdue rehabilitation of Aristotle’s signature improvement upon the Empedoclean worldview, which was itself an improvement upon

that of Parmenides, who held that the concept of ‘becoming’ was pure illusion. The logical first principles are the principle of non-contradiction (PNC) and the principle of the excluded middle (PEM), without whose presupposition the correlation of causal relation and logical implication would remain wholly unfounded, as Hume made so abundantly clear. Science requires that conclusions follow both causally *and* logically from premises and not merely by conjunction, either random or constant; quantum mechanics, by the Heisenberg uncertainty principle, requires that the final outcome state be not only subsequent to the evolution but consequent of it.

These two categories of first principles, ontological and logical, are infused throughout Whitehead’s *Categoreal Obligations*¹². Their governance of the mechanics of Whiteheadian concrescence, in the Platonic sense of *μεθεξις* and *μιμησις*, can be closely correlated with their governance of quantum mechanics, both logically and ontologically. The conceptual scientific difficulties they relieve with respect to the problem of measurement and state reduction are, as has been discussed, similarly relieved metaphysically. Though the Platonic chasm is not bridged certainly, it is bridged speculatively; quantum mechanics and Whitehead’s metaphysical scheme are both essays—attempts at crossing, built upon reasonable yet necessarily presupposed first principles. Contingent, mutable phenomena are thus correlated with necessary, immutable principles. What appears to be is thus correlated with what is reasoned to be. Description and explanation find their intersection. That the first principles cannot be accounted for by the mathematical, physical, and metaphysical schemes that presuppose them should not be considered a liability for scientific explanation, for logically it could not be otherwise. Indeed, it is only by way of the first principles that incomplete and often incompatible scientific descriptions of reality such those given by classical and quantum mechanics rise to the level of coherent, albeit ineluctably speculative, explanation.

¹² One important ontological difference, however, is that for Whitehead, actuality and potentiality are more precisely understood as mutually implicative (‘dipolar’) *features* of every ‘final real thing’ / ‘actual occasion’ rather than mutually exclusive ‘*species* of reality.’ There are not, in other words, two fundamental ‘types’ of ‘final real thing’ for Whitehead, one ‘actual’ and one ‘potential.’ Every Whiteheadian ‘final real thing’ entails both actuality and potentiality as fundamental, mutually implicative features. Every actual occasion, for Whitehead, is a ‘subject-superject’—a ‘subject’ in its potency for becoming, and a ‘superject’ in its terminal actualization as settled fact.

PART II

The Mechanics of Concrecence:
Quantum Theory and Process Metaphysics

If, indeed, those interpretations of quantum mechanics based on the ‘decoherence effect’ are best understood as demonstrating the compatibility of classical and quantum mechanics by way of a novel ontological framework, it must be a framework wherein the classical mechanistic-materialistic description of nature is shown to be a conceptual abstraction from a more fundamental quantum mechanical description. Accordingly, their chief benefit lies in the philosophical coherence they afford quantum theory, such that the interpretation’s most fundamental concepts become mutually implicative. Since, however, the decoherence-based interpretations were constructed in the realm of theoretical physics rather than that of philosophy, the novel ontological implications of these interpretations have not yet been thoroughly examined.

In *Quantum Mechanics and the Philosophy of Alfred North Whitehead*, (Fordham University Press, 2004), I suggested that these philosophical innovations correlate closely with those proposed by Alfred North Whitehead in *Process and Reality* (Macmillan, 1929; The Free Press, 1978). What follows here is an introductory treatment of the analysis presented in the book, wherein quantum mechanics is portrayed as a fundamental physical exemplification of Whitehead’s cosmological scheme. The mathematical formalism of quantum mechanics is thus offered as a heuristically useful representation of the mechanics of Whiteheadian metaphysics, and likewise the latter can be taken as a heuristically useful explication of quantum mechanics. (Given this thesis, and since this chapter is intended to be accessible to non-specialists in physics and mathematics, some technical and mathematical concepts will be presented in introductory fashion, with the majority of formulae relegated to footnotes.)

Fundamentally, the decoherence interpretations of quantum mechanics and Whitehead’s cosmological scheme both describe a process productive of the actualization of potentia in three stages:

1. An initial phase consisting of the integration, into potential states, of all facts relative to a particular fact or subsystem of facts.
2. A supplementary phase, whereby potential facts incapable of integration are eliminated via negative selection. The result is a matrix of mutually exclusive, valued potential integrations—i.e., a matrix of potential states or potential forms of facts, valued as probabilities.
3. The anticipated actualization of one of these integrations, according to the valuations qualifying each, in satisfaction of the evolution and its aim—the latter as evinced by the probabilistic nature of these valuations.

Conceptual correlations

In both the decoherence interpretations and Whitehead’s cosmology, a world of existing, mutually interrelated facts is presupposed. Both attempt to deduce the forms of facts of experience, rather than the form *and* the facts as in other interpretations of quantum mechanics—i.e., those which posit a physical dynamical mechanism (stochastic field fluctuations, etc.) as

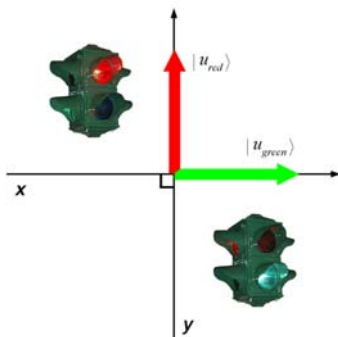
causative of wave packet collapse to a unique state. In other words, neither the decoherence interpretations nor the Whiteheadian cosmology ever attempts to account for the existence of facts; neither is concerned with accounting for the actualization of potentia, but rather with describing the valuation of potentia. In both the decoherence interpretations of quantum mechanics and Whiteheadian metaphysics, then, actualities and potentia constitute two fundamental aspects of reality.

Further, by their necessary mutual interrelations, the inclusion of actualities or facts (Whitehead's 'positive prehension' or 'feeling' of facts as 'data') in the act of measurement / state specification, somehow entails the following:

- a. all other facts and their associated potentia—either in their inclusion in the specification, or their necessary exclusion from the specification. This requirement is reflected in Whitehead's 'Principle of Relativity' and his 'Ontological Principle,' and in quantum mechanics by the Schrödinger equation's exclusive applicability to closed systems, with the universe being the only such system. The exclusions relate to the process of negative selection productive of the decoherence effect, to be discussed presently, and Whitehead refers to these eliminations as 'negative prehensions.' Their form and function with respect to environmental degrees of freedom are identical to those related to the process of decoherence.
- b. the evolution of the system of all facts into a novel fact—namely, a maximal specification (the 'state' specification) of the relevant facts (those not excluded by decoherence or 'negatively prehended' in Whitehead's terminology.) State specification—the maximal specification of many facts via the necessary exclusion of some facts—thus entails the evolution of a novel fact—namely, a unification of the facts specified.
- c. the requirement that this evolution proceed relative to a given fact, typically belonging to a particular subsystem of facts. In quantum mechanics, these are, respectively, the 'indexical eventuality' and the 'measuring apparatus'; Whitehead's equivalent term is, simply, the prehending subject. This requirement is given in Whitehead's 'Ontological Principle' and 'Category of Subjective Unity'; their correlates in quantum mechanics—the necessary relation of a state evolution to some preferred basis characteristic of the measuring apparatus—has often been misapprehended as a principle of sheer subjectivity, the source of the familiar lamentations that quantum mechanics destroys the objective reality of the world.

Quantum Mechanical State Evolution

The 'state' of a system is a maximal specification of the facts or actualities comprised by the system. The state of any system in quantum mechanics is represented by a vector of unit length in Hilbert space—an abstract linear vector space which, in the idealized case of an old-fashioned, red-green traffic signal, can be depicted via a simple x - y Cartesian coordinate system.



The benefit of using Hilbert spaces in quantum mechanics is that these spaces are capable of representing, in a mathematically useful way, potentia as well as actualities and their relationship in a given system. This representation is based on two simple principles:

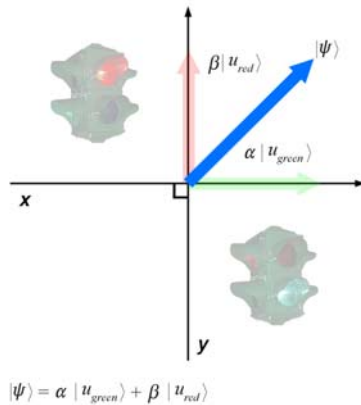
1. Every physical system can be represented by a unique Hilbert space \mathcal{H}_S and the state S of a given physical system (again, ‘state’ being the maximal specification of every fact/actuality/observable associated with the system) can be represented by a single vector $|u\rangle$ of unit length in the system’s Hilbert space.
2. In a measurement interaction involving the system, there is a one-to-one correspondence between the number of probability-valuated outcome system states and the number of dimensions comprised by the Hilbert space.

In the case of our highly-idealized traffic light system which has two potential states S , then, the associated Hilbert space has only two dimensions: One represents ‘ $S = green$,’ and the other ‘ $S = red$.’ Thus, a vector of unit length $|u_x\rangle$ along the x-axis represents ‘ $S = green$ ’ and a vector of unit length $|u_y\rangle$ along the y-axis represents ‘ $S = red$.’ The fact that these are mutually orthogonal vectors is representative of the *mutual exclusivity* of the states. It is crucial to note that ontologically, the desideratum of the mutual exclusivity of probable alternative outcome states is a *presupposed principle*—a first principle of quantum mechanics in that it has not, as yet, been deduced from some more fundamental physical principle. Alternatively, many have argued that the mutual exclusivity of outcome states (i.e., the proscription against ‘real life’ superpositions) is merely an epistemic phenomenon and thus ontologically insignificant. The approaches of Everett and Bohr, among others, are representative of this position. But for those who argue for the ontological significance of quantum mechanics, the mutual exclusivity of probable outcome states remains a necessarily presupposed first principle. More important, it is a first principle that exemplifies the logical first principle of non-contradiction (PNC).

Similarly, and in accord with Principle 2 above, since any Hilbert space of n dimensions includes only n mutually orthogonal vectors, the orthogonality of $|u_x\rangle$ and $|u_y\rangle$ also indicates that these two states form an *exhaustive set*. Likewise, if this desideratum be ontologically significant, it is a necessarily presupposed first principle of quantum mechanics. And like the mutual exclusivity of probable outcome states, the exhaustiveness of the set of probable outcome states for any particular measurement interaction can similarly be derived from a counterpart first principle of logic—in this case, the principle of the excluded middle (PEM). PNC and PEM are also first principles of Whiteheadian metaphysics and find their exemplification in a number of his ‘Categorical Obligations,’ as will be discussed later in this essay.

In a less idealized Hilbert space, one would simply group mutually orthogonal vectors into subspaces, where any vector belonging to the subspace \mathcal{E} is orthogonal to any vector in subspace \mathcal{E}^\perp . This would imply, however, that there exist vectors of unit length—i.e., vectors that represent real states of a physical system—that belong *neither* to \mathcal{E} nor to \mathcal{E}^\perp for a given fact. There are, in other words—at least in the early phases of quantum mechanical state evolution—real physical states wherein the actuality of a given potential fact is *objectively indefinite*. With respect to the idealized traffic light system, where a unit-length vector $|u_{green}\rangle$ along the x-axis represents the state $S = green$, and a unit-length vector $|u_{red}\rangle$ along the y-axis represents $S = red$, one might ask: What of the unit-length vector $|\psi\rangle$, which lies neither on the x nor the y axis? Since it is a vector of unit length, it represents a real potential physical state

according to the quantum theory; but it represents a potential physical state wherein the traffic signal is neither green nor red.



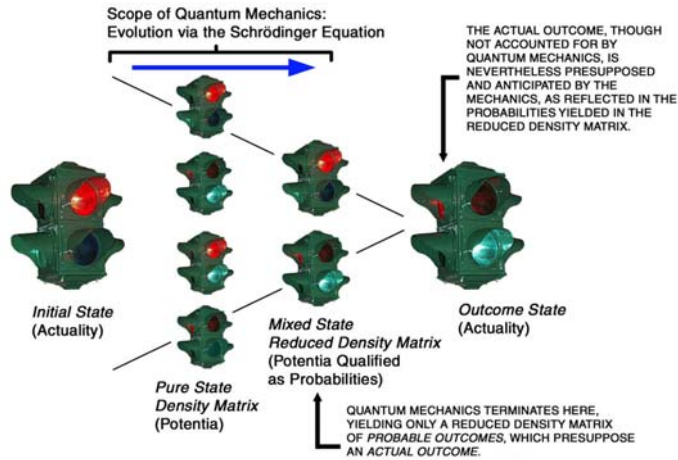
Quantum mechanics describes the evolution of such ‘pure states’ $|\psi\rangle$, whose potential facts are entangled in this evolved superposition, into a finite set of mutually exclusive (by PNC) and exhaustive (by PEM) states as represented by a set of mutually orthogonal vectors. In quantum mechanics, each of these potential outcome states becomes valued according to a probability, and all of the alternative outcome states together are referred to collectively as a ‘mixed state,’ so named because unlike a pure state $|\psi\rangle$, the mixed state comprises a mixture of probability valued, mutually exclusive, exhaustive outcome states. In the case of the traffic signal example, the pure state $|\psi\rangle$ evolves to become one of these component states (or *eigenstates*) of the mixed state, wherein the signal is definitely either green $|u_{green}\rangle$ or red $|u_{red}\rangle$ upon observation (measurement).

In other words, in the initial, ‘pure state’ $|\psi\rangle$, the possible outcome states are correlated, or superposed.¹³ But upon state evolution, the correlated pure state is reduced by some selection process to yield a logical, PNC-PEM compliant mixed state, expressible as a density matrix of separate, uncorrelated mutually exclusive and exhaustive outcomes, each valued as a probability.¹⁴

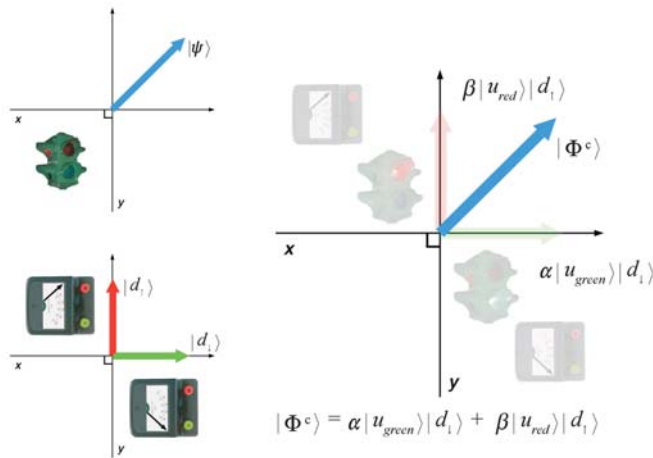
It is important to note, however, that quantum mechanics does not describe the evolution of the mixed state to a unique state; quantum mechanics only describes the evolution of the much broader pure state superposition to the matrix of probable measurement outcomes subsumed by the mixed state. Put another way, quantum mechanics does not include a mechanism for the actualization of potentia; it merely describes the *valuation* of potentia—the valuation of the alternative potential eigenstates belonging to the mixed state, such that these alternative potential states become *probabilities* and not just potentia.

¹³ This is expressed as a sum of the associated vectors: $|\psi\rangle = \alpha |u_{green}\rangle + \beta |u_{red}\rangle$ with $|\alpha|^2 + |\beta|^2 = 1$. The probability valuation qualifying each eigenstate of the mixture is indicated by adding the complex coefficients α and β , which indicate the length of each respective vector.

¹⁴ $\rho = |\alpha|^2 |u_{green}\rangle\langle u_{green}| + |\beta|^2 |u_{red}\rangle\langle u_{red}|$



To the traffic signal system S , we shall add a detector system D , which is the instrument by which we are able to measure the color of the traffic signal. S and D together constitute a composite system whose combined Hilbert spaces form a tensor product space such that S and D together will evolve in a correlated manner.¹⁵ And as before, a probability is assigned to each of these alternative states, and these probable outcome states are grouped within a density matrix.¹⁶



There are, however, two important ontological difficulties which one might infer from the formalism presented thus far:

¹⁵ The composite, initial S and D system $|\Phi^i\rangle$ whose pure state evolves as:

$$|\Phi^i\rangle = (\alpha|u_{green}\rangle + \beta|u_{red}\rangle)|d_1\rangle \Rightarrow \alpha|u_{green}\rangle|d_1\rangle + \beta|u_{red}\rangle|d_1\rangle = |\Phi^c\rangle$$

¹⁶ $\rho = |\alpha|^2 |u_{green}\rangle\langle u_{green}| |d_1\rangle\langle d_1| + |\beta|^2 |u_{red}\rangle\langle u_{red}| |d_1\rangle\langle d_1|$

1. Why does the pure state always evolve according to the particular outcome forms of the *detector* (i.e., according to its ‘preferred basis’ or ‘pointer basis’) rather than some other potential form associated with the system? Why, in other words, do measurements of certain physical quantities produce value-definite ‘up’ or ‘down’ pointer indications on the detector, and why is it that the state always evolves in terms of *these* particular quantities instead of some other?
2. Why does the density matrix of the mixed state always subsume sensible, mutually exclusive and exhaustive alternative states? Why can’t the mixed state ever subsume nonsensical states such as $\alpha|u_{green}\rangle|d_1\rangle$ or superpositions of states? And what destroys these states? If, as is commonly held, it is the act of measurement by a classically describable apparatus (or by some interpretations, a human observer) which destroys such coherent superpositions, how can quantum mechanics be a universal theory?

Answers to both of these ontological difficulties can be found in the function of the decoherence effect in quantum mechanics.

Decoherence

‘Decoherence’ refers to the outcome of a process whereby a coherent pure state superposition $|\psi\rangle$ of *potential* outcome states is distilled into a ‘decoherent’ set of mutually exclusive and exhaustive *probable* outcome states such as $\alpha|u_{green}\rangle$, $\beta|u_{red}\rangle$, etc, characteristic of the mixed state.

There are two important conceptual implications of this process which answer the two problems presented above, respectively:

1. Quantum mechanics does not merely describe the mutual interrelations among all facts comprised by a given composite system $S + D$; quantum mechanics describes, rather, the evolution of the pure state of $S + D$ *relative to a particular fact belonging to this composite system*—or, more accurately, relative to the interrelations between this particular fact and all other facts belonging to the composite system.

In quantum mechanics, this ‘particular fact’—the ‘indexical eventuality’—always belongs to the detector. Thus, the mixed state always reflects the preferred basis of the detector since the state of the composite system evolves relative to an indexical eventuality belonging to it. The grouping of mixed state vectors into orthogonal or mutually exclusive and exhaustive subspaces \mathcal{E} and \mathcal{E}^\perp exemplifies this relativity, where all potential states sharing the indexical eventuality $|d_1\rangle$, for example, belong to \mathcal{E} and all others belong to \mathcal{E}^\perp . This evolution of the pure state *relative to a particular fact* is central to the elimination of superpositions of interfering, ‘coherent’ states via negative selection discussed below; the only potential outcome states which remain—those constituting the mixed state—are, as a result, non-interfering, ‘decoherent’ potential outcome states, which have been valuated as probabilities.

2. The correlation of the measured system (S) and the detector (D) with the environment encompassing both (E) and its manifold degrees of freedom destroys coherent superpositions of mutually interfering states.

This crucial function of the environment in quantum mechanical measurement interactions has, for the most part, been ignored over the years, though its significance was alluded to even in the early days of the quantum theory. Heisenberg, for example, wrote that the superposition or interference of potentia, “which is the most characteristic phenomenon of quantum theory, is destroyed by the partly indefinable and irreversible interactions of the system with the measuring apparatus and the rest of the world.”¹⁷

Indeed, the universe, since it is the only truly closed system, is the only system to which quantum mechanics is ontologically significant; therefore the grouping of various facts within this closed system into ‘system’ ‘apparatus’ and ‘environment’ subsystems is purely arbitrary. Thus, the evolution of the state of a measured system is, in fact, the evolution of the state of the universe itself; its evolution relative to a given indexical eventuality belonging to a particular measuring apparatus is merely its evolution relative to a particular fact belonging to itself. The correlation among facts belonging to ‘system,’ ‘detector,’ and ‘environment,’ then, is easily comprehended by virtue of the fact that as the closed system of the universe evolves, so must all the facts subsumed by it, however they might be grouped and whatever they might be named. These last two points are clearly expressed by Heisenberg in the following:

“The measuring device...contains all the uncertainties concerning the microscopic structure of the device which we know from thermodynamics, and since the device is connected with the rest of the world, it contains in fact the uncertainties of the microscopic structure of the whole world.”¹⁸

“Decoherence results from a negative selection process that dynamically eliminates nonclassical states,” writes Wojciech Zurek, who maintains that decoherence is a consequence of the universe’s role as the only truly closed system, which guarantees the ineluctable ‘openness’ of every subsystem within it. “This consequence of openness is critical in the interpretation of quantum theory,” Zurek continues, “but seems to have gone unnoticed for a long time.”¹⁹ For Zurek, the key to understanding the negative selection mechanism of decoherence is a supplemental process, suggested by von Neumann²⁰—his ‘Process 1’—whereby the reduced density matrix of the mixed state²¹ explicitly evolves from a larger, correlated, pure state density matrix. Unlike the reduced matrix, this pure state density matrix contains nonsensical, ‘mutually interfering’ states (noted in boldface) which must be eliminated²²

Making explicit this evolution of the state vector from the correlated pure state $|\Phi^c\rangle$ and its pure state density matrix ρ^c to the mixed state and its reduced density matrix ρ^r is useful in that one is able to attempt to *account for*, rather than merely acknowledge, the elimination from

¹⁷ Werner Heisenberg. *Physics and Philosophy*. New York (Harper Torchbooks, 1958), 143.

¹⁸ Ibid, 53.

¹⁹ Wojciech Zurek. “Letters” *Physics Today*, 46, 4, 1993, 84.

²⁰ John von Neumann. *Mathematical Foundations of Quantum Mechanics*. Princeton: Princeton University Press, 1955.

²¹ $\rho^r = |\alpha|^2 |u_{green}\rangle\langle u_{green}| |d_1\rangle\langle d_1| + |\beta|^2 |u_{red}\rangle\langle u_{red}| |d_1\rangle\langle d_1|$

²² $\rho^c = |\alpha|^2 |u_{green}\rangle\langle u_{green}| |d_1\rangle\langle d_1| + \alpha\beta |u_{green}\rangle\langle u_{red}| |d_1\rangle\langle d_1|$
 $+ \alpha^*\beta |u_{red}\rangle\langle u_{green}| |d_1\rangle\langle d_1| + |\beta|^2 |u_{red}\rangle\langle u_{red}| |d_1\rangle\langle d_1|$

ρ^c of the nonsensical, mutually interfering states incapable of integration in the reduced density matrix. Again, the off-diagonal terms (in boldface in footnote 22 on p. 18) represent these nonsensical states, whose vectors are mutually non-orthogonal. Typically, one merely cancels out these off-diagonal terms, yielding the reduced density matrix; however, the ontological interpretations that make use of the decoherence effect suggest an ontologically significant process by which the interaction of the measured system with its measuring apparatus and its environment produces the necessary cancellations.²³

The Hilbert spaces describing our traffic signal and detector by themselves only span two dimensions, which are not sufficient to produce the cancellations needed to eliminate unwanted superpositions of interfering states. But by correlating our system and detector with the environment and its Hilbert space of practically infinite dimensions, we are able to produce enough potential states of $|\Psi\rangle$ such that most of these are mutually interfering and cancel each other out, thereby eliminating superpositions of interfering states. With respect to the density matrix, this cancellation is represented via a trace over of the uncontrolled and unmeasured degrees of freedom supplied by the environment.

Thus, the interrelation of environmental facts with the facts comprised by our system and detector continuously reduces any coherent, interfering superpositions of states relative to the preferred basis $|d_1\rangle$ and $\langle d_1|$, such that the only alternative states in the reduced density matrix are mutually exclusive and exhaustive, ‘sensible’ states, each valuated according to a probability. The concept of ‘measurement,’ then, is most fundamentally understood as the interrelation of actualities. ‘Environmental’ actualities are thus as capable of ‘making measurements’ as those actualities constituting a measuring apparatus or human observer. “An effective superselection rule has emerged,” Zurek writes. “Decoherence prevents superpositions of the preferred basis states from persisting. Moreover, we have obtained all this—or so it appears—without having to appeal to anything beyond the ordinary, unitary Schrödinger evolution.”²⁴

It is important to note, though, that like other interpretations of quantum mechanics, the decoherence-based interpretations do not account for the existence of actualities—either those constituting the initial state, or that of the unitary outcome state actualized from among other potential outcome states in the reduced density matrix. But unlike other interpretations which consider this to be a deficiency or a problem to be solved (i.e., the ‘problem’ of state reduction...) the decoherence-based interpretations characterize quantum mechanics as describing the evolution of potentia to valuated probability; and as such, these interpretations make explicit their logical predication upon the *a priori* existence of facts—a predication implied, for example, in the following three concepts:

1. state *evolution*—i.e., evolution from presupposed initial fact(s), through a matrix of potentia, to a reduced matrix of potentia valuated as probabilities, to subsequent and consequent *anticipated* fact;

²³ In Zurek’s Environmental Superselection interpretation (Zurek 1991, 36), for example, the interaction of the environment $|E_0\rangle$ with $|\Phi^c\rangle$ is described as: $|\Phi^c\rangle |E_0\rangle = (\alpha |u_{green}\rangle |d_1\rangle + \beta |u_{red}\rangle |d_1\rangle) |E_0\rangle$

$$\Rightarrow \alpha |u_{green}\rangle |d_1\rangle |E_1\rangle + \beta |u_{red}\rangle |d_1\rangle |E_1\rangle = |\Psi\rangle$$

²⁴ Wojciech Zurek. “Decoherence and the Transition from the Quantum to the Classical” *Physics Today*, 44, 10, 1991, 40.

2. *probability* that a presupposed antecedent fact will *become* a particular potential novel fact according to a quantifiable valuation. Murray Gell-Mann has suggested a useful analogy wherein the probability that a certain horse will win a race logically presupposes, 1. the existence of the horse, the racetrack, and indeed, the universe itself; and 2. an anticipated winner.²⁵

It is the probability valuation of the mutually exclusive and exhaustive potential outcome states which governs, and therefore guarantees, within the framework of quantum mechanics, the actualization of a unique outcome state. The entire process, therefore, occurs relative to both, a) the indexical eventuality participant in the system whose state is being specified; and b) the indexical eventuality as participant in the satisfaction of the probability valuations terminal of quantum mechanics. For as probabilities, these valuations presuppose and anticipate this satisfaction. It is the valuation of potentia, then, and the process productive of it--rather than the actualization of potentia--which quantum mechanics describes.

3. the concept of *histories of states* as serial routes of state evolutions—i.e., histories of facts whose perpetual augmentation by novel facts is also presupposed. The elimination of interfering potentia and the probability-valuation of those which remain, via the environmental correlations and trace-over described above, is thus seen as the elimination of interfering *potential histories*. Separate systems with separate histories, by virtue of their correlation with a shared environment (i.e., the universe), necessarily entail many shared potential facts. And since these shared potential facts must be mutually consistent, so must those histories which include them—lest nature become overrun with violations of the principle of non-contradiction which forms the very core of logic. Interfering potential histories, those which are non-mutually exclusive and exhaustive, are thus eliminated by integration via environmental correlation. Thus, the mutual historical consistency of multiple systems, even those which are spatially well-separated, derives in large part from their being englobed by a larger, shared ‘environmental history.’

This concept of decoherent, consistent histories associated with environmental correlations was first proposed by Robert Griffiths in 1984,²⁶ with later contributions by other theorists including Roland Omnès,²⁷ and Murray Gell-Mann & James Hartle with their ‘decoherent histories’ interpretation.²⁸

Quantum Mechanics and Whiteheadian Concrescence

At its heart, measurement or state specification entails the anticipated actualization (Whiteheadian ‘concrescence’) of one novel potential fact/entity from many valued potential

²⁵ Gell-Mann 1994, 141

²⁶ Robert J. Griffiths. *Stat Phys.* 36, 1984, 219. See also, Griffiths, Robert J. *Consistent Quantum Theory*. Cambridge: Cambridge University Press, 2002.

²⁷ Roland Omnès. *The Interpretation of Quantum Mechanics*. Princeton: Princeton University Press, 1994.

²⁸ Murray Gell-Mann, James Hartle. "Strong Decoherence" *Contribution to the Proceedings of the 4th Drexel Symposium on Quantum Non-Integrability-The Quantum-Classical Correspondence*, Drexel University, September, 1994.

facts/entities which themselves arise from antecedent facts (Whiteheadian ‘data’); and it is understood that the quantum mechanical description of this evolution terminates in a matrix of probability valuations, anticipative of a final unitary reduction to a single actuality. Ultimately, then, concrescence/state evolution is a unitary evolution, from actualities to actuality. But when analyzed into sub-phases, both concrescence and state evolution entail fundamental non-unitary evolutions consistent with von Neumann’s conception of quantum mechanics as most fundamentally a non-unitary state reduction productive of a unitary reduction. It is an evolution from:

- a. a multiplicity of the actual many—i.e., $|\Psi\rangle$ —to...
- b. ...a matrix of potential ‘formal’ (in the sense of applying a ‘form’ to the facts) integrations or unifications of the many (Whitehead’s term is propositional ‘transmutations’ of the many, and he also groups these into matrices¹¹); each of these potential integrations is described in quantum mechanics as a projection of a vector representing the actual, evolving multiplicity of facts onto a vector (or subspace) representing a potential ‘formally integrated’ eigenstate.

In describing our idealized traffic signal system, for example, we have:

$$|\Psi\rangle = \alpha|u_{green}\rangle|d_1\rangle|E_1\rangle + \beta|u_{red}\rangle|d_1\rangle|E_1\rangle$$

where the first phase of this evolution yields the pure state density matrix—an ‘unqualified propositional matrix’ in Whiteheadian metaphysics²⁹:

$$\begin{aligned} \rho^c &= |\Psi\rangle\langle\Psi| \\ &= |\alpha|^2|u_{green}\rangle\langle u_{green}||d_1\rangle\langle d_1||E_1\rangle\langle E_1| + \alpha\beta|u_{green}\rangle\langle u_{red}||d_1\rangle\langle d_1||E_1\rangle\langle E_1| \\ &\quad + \alpha^*\beta|u_{red}\rangle\langle u_{green}||d_1\rangle\langle d_1||E_1\rangle\langle E_1| + |\beta|^2|u_{red}\rangle\langle u_{red}||d_1\rangle\langle d_1||E_1\rangle\langle E_1| \end{aligned}$$

These four terms are, in Whiteheadian language, four ‘subjective forms’ as ‘pure potentia’; but only two of these are ‘real potentia’ in the Whiteheadian language, as the two off-diagonal terms in boldface represent, by their violation of the logical principle of non-contradiction (PNC), data incompatible for integration which therefore must be eliminated via negative selection in a subsequent phase. I propose that Whitehead’s method of elimination via negative selection, predicated on the prehension of environmental degrees of freedom, is mirrored precisely by the decoherence effect and its predication on the incorporation of environmental degrees of freedom in quantum mechanical state evolution.

It’s also interesting to note that the Whiteheadian analog of the actual multiplicity’s projection onto a potential formal integration is ‘ingression’—where a potential formal integration arises from the ingression of a specific ‘potentiality of definiteness’ via a ‘conceptual prehension’ of that specific potentiality of definiteness (Whitehead also refers to these potentia as ‘eternal objects.’) But whereas in quantum mechanics, the state vector $|\Psi\rangle$ representing the actual multiplicity of facts is *projected onto* the potential integration (i.e., projected onto the

²⁹

Whitehead 1978, 285.

eigenvector representing the eigenstate), in Whitehead's scheme it is the latter (the eigenstate as 'potentiality of definiteness') which *ingresses into* the prehensions of the actual multiplicity. This difference reflects Whitehead's concern with the origin of these potentia, for if they ingress into the evolution, they must be thought of as coming from somewhere. The eigenstate, or object of projection in quantum mechanics is, in contrast, simply extant. This difference aside, Whiteheadian vector 'ingression' and quantum mechanical vector 'projection' are conceptually equivalent—as are the terms 'eternal object' and 'potential fact.'

- c. A re-integration of these integrations into a matrix of 'qualified propositional'³⁰ transmutations, involving a process of negative selection wherein 'negative prehensions' of potentia incapable of further integration are eliminated.

In quantum mechanics, this re-integration is represented by the evolution of the pure state density matrix (given above) to the reduced matrix.³¹ The off-diagonal terms are eliminated in this reduction by virtue of their correlations with manifold environmental degrees of freedom. This process of negative selection is described by the trace-over of these degrees of freedom³² and evinces the 'Principle of Relativity' so crucial to Whitehead's cosmology: Every fact is a potential determinant in the becoming of every new fact.

Each of the two decoherent potential outcome states yielded by this process of negative selection—i.e., each potential Whiteheadian 'transmutation'³³—is thus a 'qualified propositional' potential 'form' into which the potential facts of $|\Psi\rangle$ will ultimately evolve. Whitehead terms these 'subjective forms' and as applied to quantum mechanics, the term 'subjective' refers to the fact that the 'form' of each potential outcome state is reflected in the preferred basis as determined by the indexical eventuality (Whitehead's 'prehending subject') constituent of the measuring apparatus (*d*). Again, it is only the *form* that is thus subjective—for any number of different devices with different preferred bases could be used to measure a given system, and any number of different people with their own 'mental preferred bases' could interpret (measure) the different readings of the different devices, and so on down the von Neumann chain of actualizations. The potential facts to which each subjective form pertains, however, are initially 'given' by the objective facts constitutive of the world antecedent to the concrescence at hand. Thus, again, the 'subjective form' of a preferred basis is in no way demonstrative of sheer subjectivity—i.e., the evolution of novel facts as *determined* by a subject; it is, rather, demonstrative of the evolution of novel facts jointly determined by both the world of facts antecedent to the evolution and the character of the subject prehending this evolution by virtue of its inclusion in it. According to Whitehead's 'Ontological Principle':

³⁰ Ibid.

³¹
$$\rho^r = |\alpha|^2 |u_{green}\rangle\langle u_{green}| |d_1\rangle\langle d_1| + |\beta|^2 |u_{red}\rangle\langle u_{red}| |d_1\rangle\langle d_1|$$
 where $|\alpha|^2 + |\beta|^2 = 1$

³²
$$\text{Tr}_E |\Psi\rangle\langle\Psi| = \sum_i \langle E_i|\Psi\rangle\langle\Psi|E_i\rangle = \rho^r$$

³³ $|\alpha|^2 |u_{green}\rangle\langle u_{green}| |d_1\rangle\langle d_1|$ and $|\beta|^2 |u_{red}\rangle\langle u_{red}| |d_1\rangle\langle d_1|$

“Every condition to which the process of becoming conforms in any particular instance, has its reason either in the character of some actual entity in the actual world of that concrescence, or in the character of the subject which is in process of concrescence...”

³⁴ The actual world is the ‘objective content’ of each new creation.” ³⁵

The evolution thus proceeds to and terminates with what Whitehead terms the ‘satisfaction,’ which in quantum mechanical terms is described as:

- d. The actualization of the final outcome state—i.e., one subjective form from the reduced matrix of many subjective forms—in ‘satisfaction’ of the probability valuations of the potential outcome states in the reduced matrix.

In quantum mechanics, as in Whitehead's model, this actualization is irrelevant and transparent apart from its function as a datum (fact) in a subsequent measurement. Again, this is simply because both Whitehead's process of concrescence and quantum mechanics presuppose the existence of facts, and thus cannot account for them. For Whitehead, ‘satisfaction’ entails “the notion of the ‘entity as concrete’ abstracted from the ‘process of concrescence’; it is the outcome separated from the process, thereby losing the actuality of the atomic entity, which is both process and outcome.” ³⁶ Thus, the probability valuations of quantum mechanics describe probabilities that a given potential outcome state *will be actual* upon observation—implying a subsequent evolution and an interminable evolution of such evolutions. Every fact or system of facts in quantum mechanics, then, subsumes and implies both an initial state and a final state; there can be no state specification *S* without reference, implicit or explicit, to *S* initial and *S* final. This is reflected in Whitehead's scheme by referring to the ‘subject’ as the ‘subject-superject’:

“The ‘satisfaction’ is the ‘superject’ rather than the ‘substance’ or the ‘subject.’ It closes up the entity; and yet is the superject adding its character to the creativity whereby there is a becoming of entities superseding the one in question...” ³⁷

“An actual entity is to be conceived as both a subject presiding over its own immediacy of becoming, and a superject which is the atomic creature exercising its function of objective immortality...” ³⁸ It is a subject-superject, and neither half of this description can for a moment be lost sight of... ³⁹ [The superject is that which] adds a determinate condition to the settlement for the future beyond itself.” ⁴⁰

Thus, the process of concrescence is never terminated by actualization/satisfaction; it is, rather, both begun and concluded with it, such that the many facts and their associated potentia become one novel state (a novel fact), and are thus increased, historically, by one, so that “the

³⁴ Ibid, 24.

³⁵ Ibid, 65.

³⁶ Ibid, 84.

³⁷ Ibid.

³⁸ Ibid, 45.

³⁹ Ibid, 29.

⁴⁰ Ibid, 150.

oneness of the universe, and the oneness of each element in the universe, repeat themselves to the crack of doom in the creative advance from creature to creature.”⁴¹

“The atomic actualities individually express the genetic unity of the universe. The world expands through recurrent unifications of itself, each, by the addition of itself, automatically recreating the multiplicity anew.”⁴²

Decoherence and Whiteheadian ‘Transmutation’

Returning to the quantum mechanical expression of concrescence as:

$|\Psi\rangle = \alpha|u_{green}\rangle|d_1\rangle|E_1\rangle + \beta|u_{red}\rangle|d_1\rangle|E_1\rangle$: This expression, in both the decoherence-based interpretations of quantum mechanics and in Whitehead’s scheme, presupposes a process of negative selection via ‘negative prehensions.’ This process, as we saw above, is expressed via the use of matrices of potentia—or more precisely, matrices of alternative integrations of potentia. These integrations are exemplifications of the Whiteheadian ‘subjective forms’ of potentia, given that these potentia are expressed in terms of $|d\rangle$ —i.e., relative to $|d\rangle$ as the indexical eventuality / prehending subject. The pure state density matrix contains all the ingressed potentia, pure and real, related to the data of the correlated system-apparatus-environment.⁴³

Some of these potentia are capable of integration into the mutually exclusive subjective forms $\alpha|u_{green}\rangle|d_1\rangle|E_1\rangle$ and $\beta|u_{red}\rangle|d_1\rangle|E_1\rangle$; and others are incapable of such integration because of their mutual non-exclusivity (interference) and thus constitute coherent superpositions of potentia. These are represented by the off-diagonal terms in boldface and are the nonsensical subjective forms which are eliminated from the concrescing evolution by virtue of the excess prehensions of environmental data they include—again, ‘excess’ relative to the prehending subject/indexical eventuality. These potentia are eliminated, writes Whitehead, via

“...a massive average objectification of a nexus, while eliminating the detailed diversities of the various members of the nexus in question. This method, in fact, employs the device of blocking out unwelcome detail. It depends on the fundamental truth that objectification is abstraction. It utilizes this abstraction inherent in objectification so as to dismiss the thwarting elements of a nexus into negative prehensions. At the same time the complex intensity in the structured society is supported by the massive objectifications of the many environmental nexūs, each in its unity as one nexus, and not in its multiplicity as many actual occasions.

“This mode of solution requires the intervention of mentality [i.e., activity of the ‘Mental Pole’ or ‘Supplementary Phase’ of concrescence—not conscious or anthropic mentality]

⁴¹ Ibid, 228.

⁴² Ibid, 286.

⁴³ $\rho^c = |\Psi\rangle\langle\Psi|$

$$= |\alpha|^2 |u_{green}\rangle\langle u_{green}||d_1\rangle\langle d_1||E_1\rangle\langle E_1| + \alpha\beta^* |u_{green}\rangle\langle u_{red}||d_1\rangle\langle d_1||E_1\rangle\langle E_1| \\ + \alpha^*\beta |u_{red}\rangle\langle u_{green}||d_1\rangle\langle d_1||E_1\rangle\langle E_1| + |\beta|^2 |u_{red}\rangle\langle u_{red}||d_1\rangle\langle d_1||E_1\rangle\langle E_1|$$

operating in accordance with the Category of Transmutation. It ignores diversity of detail by overwhelming the nexus by means of some congenial uniformity which pervades it. The environment may then change indefinitely so far as concerns the ignored details—so long as they can be ignored.

“The close association of all physical bodies, organic and inorganic alike...suggests that this development of mentality is characteristic of the actual occasions which make up the structured societies we know as ‘material bodies.’”⁴⁴

The mathematical analog of the Category of Transmutation is, as we have seen, the ‘trace over’ of the potentia in the pure state density matrix such that the ‘detailed diversities’ and ‘thwarting elements’ of the integration stemming from the environmental correlations, represented by the off-diagonal terms, are eliminated. This yields a reduced density matrix ρ^r of mutually exclusive and exhaustive subjective forms, or valuated ‘real’ potential integrations of the system-apparatus nexus.⁴⁵

This ‘massive average objectification’ is possible mathematically for the same reason it is possible conceptually in Whitehead’s scheme; it is prefaced by an integration of a vast multiplicity of potential outcomes (owing to the manifold degrees of freedom contributed by the environment) into various ‘subjective forms’ relative to the prehending subject/indexical eventuality $|d\rangle$. In the case of our traffic light example, this yields four subjective forms:

1. $|\alpha|^2 |u_{green}\rangle\langle u_{green}||d_i\rangle\langle d_i||E_i\rangle\langle E_i|$
2. $|\beta|^2 |u_{red}\rangle\langle u_{red}||d_i\rangle\langle d_i||E_i\rangle\langle E_i|$
3. **$\alpha\beta |u_{green}\rangle\langle u_{red}||d_i\rangle\langle d_i||E_i\rangle\langle E_i|$**
4. **$\alpha^*\beta |u_{red}\rangle\langle u_{green}||d_i\rangle\langle d_i||E_i\rangle\langle E_i|$**

Each subjective form is a potential integration of all facts belonging to the nexus of facts comprising the system, the measuring apparatus, and the environment relative to the prehending subject/indexical eventuality $|d\rangle$; each potential integration, by the manifold environmental correlations, thus entails a practically infinite number of potentia—some prehended positively, others negatively—each one related to a separate environmental datum. Each of these four subjective forms consists of manifold potential integrations of these prehensions of the system-apparatus-environment nexus, but each shares a common, ‘defining characteristic’ determined by each subjective form—namely, the particular status of the indexical eventuality $|d\rangle$.

Mathematically, each subjective form is thus referred to as an ‘equivalence class’ or ‘coarse grained’ integration. And it is this grouping into equivalence classes or Whiteheadian ‘subjective forms’ which allows for the cancellations among ignored “detailed diversities,” thus “blocking out unwelcome detail” (or ‘coarse graining’ these details); and it is by these cancellations that the elimination of the interfering, incompatible potentia represented by the subjective forms 3 and 4 (in boldface above) is effected. Whitehead writes:

⁴⁴ Ibid, 101.

⁴⁵ $\rho^r = |\alpha|^2 |u_{green}\rangle\langle u_{green}||d_i\rangle\langle d_i| + |\beta|^2 |u_{red}\rangle\langle u_{red}||d_i\rangle\langle d_i|$

“The irrelevant multiplicity of detail is eliminated, and emphasis is laid on the elements of systematic order in the actual world...⁴⁶ In this process, the negative prehensions which effect the elimination are not merely negligible. The process through which a feeling passes in constituting itself, also records itself in the subjective form of the integral feeling. The negative prehensions have their own subjective forms which they contribute to the process. A feeling bears on itself the scars of its birth; it recollects as a subjective emotion its struggle for existence; it retains the impress of what it might have been, but is not. It is for this reason that what an actual entity has avoided as a datum for feeling may yet be an important part of its equipment. The actual cannot be reduced to mere matter of fact in divorce from the potential.⁴⁷

“The right co-ordination of negative prehensions is one secret of mental progress; but unless some systematic scheme of relatedness characterizes the environment, there will be nothing left whereby to constitute vivid prehension of the world.”⁴⁸

This ‘right co-ordination of negative prehensions’ via a ‘systematic scheme of relatedness’ characterizing the environment, productive of correlate co-ordinations of positive prehensions, occurs in Phase III of the concrescence (see the graphic on the last page) in accord with the Category of Transmutation, which “...ignores diversity of detail by overwhelming the nexus by means of some congenial uniformity which pervades it. The environment may then change indefinitely so far as concerns the ignored details—so long as they can be ignored.”⁴⁹

The process of decoherence as described above—via integrations of potentia into ‘equivalence classes’ or ‘subjective forms’ according to a defining characteristic—is a precise exemplification of the Category of Transmutation; for it describes the integration of a bare multiplicity of facts into a potential system (nexus) where each potential fact in the potential system shares a ‘defining characteristic’ given in the indexical eventuality of the measuring apparatus. Thus, each potential integration of this kind (a nexus with ‘social order’) is exemplified mathematically as an ‘equivalence class’ or ‘coarse-grained’ integration:

“A ‘society’...is a nexus with social order. A nexus enjoys ‘social order’ where (i) there is a common element of form illustrated in the definiteness of each of its included actual entities, and (ii) this common element of form arises in each member of the nexus by reason of the conditions imposed upon it by its prehensions of some other members of the nexus, and (iii) these prehensions impose that condition of reproduction by reason of their inclusion of positive feelings of that common form. Such a nexus is called a ‘society,’ and the common form is the ‘defining characteristic’ of the society. The notion of ‘defining characteristic’ is allied to the Aristotelian notion ‘substantial form.’”⁵⁰

And as this concept applies to the Category of Transmutation, defined by Whitehead:

“When...one, and the same, conceptual feeling is derived impartially by a prehending subject from its analogous simple physical feelings of various actual entities, then in a subsequent phase [Phase III] of integration—of these simple physical feelings together with the derivate conceptual feeling—the prehending subject may transmute the *datum* of

⁴⁶ Ibid, 254.

⁴⁷ Ibid, 226-7.

⁴⁸ Ibid, 254.

⁴⁹ Ibid, 101.

⁵⁰ Ibid, 34.

this conceptual feeling into a characteristic of some *nexus* containing those prehended actual entities, or of some part of that nexus; so that the nexus (or its part), thus qualified, is the objective datum of a feeling entertained by this prehending subject. Such a transmutation of simple physical feelings of many actualities into one physical feeling of a nexus as one, is called a ‘transmuted feeling.’⁵¹ It is evident that the complete datum of the transmuted feeling is a contrast, namely, ‘the nexus, as one, in contrast with the eternal object.’ This type of contrast is one of the meanings of the notion ‘qualification of physical substance by quality.’⁵²

The decoherence effect in quantum mechanics—via coarse-grained, alternative ‘equivalence classes’ productive of the necessary eliminations of interfering potentia—is an exemplification of the Category of Transmutation both conceptually and ‘mechanically’: Both the decoherence effect and the Category of Transmutation play an identical role in accounting for the ordered, enduring characteristics of the ‘classical’ macroscopic world, including our notion of ‘qualification of physical substance by quality’; and each ultimately provides the conceptual and mechanical means by which its fundamental characterization of nature can apply to human experience. But one must take care to avoid conflating the concept of ‘mechanism’ with the concept of ‘materialism’—a conflation which lies at the heart of the conventional connotation of ‘mechanism.’

Both quantum mechanics and Whiteheadian metaphysics describe a non-deterministic, non-materialistic process. But it is a mechanical process nonetheless, evinced in two aspects: 1. it entails a realistic physics and metaphysics, grounded upon the objective actuality of the past; 2. potentia are ontologically significant components of this process. They are integrated and re-integrated with other data into matrices of probability-valuated subjective forms according to a set of governing principles (Whitehead’s Categorical Obligations, the various projection postulates of quantum mechanics, etc.)—principles capable of representation as rule-governed, mathematically describable constructions. Thus it is a non-deterministic, non-materialistic process which both Whiteheadian concrescence and quantum mechanical state evolution describe, both conceptually and mechanically; it is mechanism devoid of misplaced concreteness.

The distinction between ‘conceptual’ and ‘mechanical’ means is important here, for Whitehead had the former in mind with respect to the Category of Transmutation more so than the latter; he was not aware, for example, of the recent quantum mechanical interpretations which use the decoherence effect to *mechanically* account for the classicality of macroscopic objects. But even though Whitehead was more interested in the Category of Transmutation conceptually as it applies to perception (i.e., its use in accounting for perceptive errors⁵³), he explicitly refrained from predicating Transmutation upon consciousness or any other exclusively anthropic feature:

“It is evident that adversion and aversion, and also the Category of Transmutation, only have importance in the case of high-grade organisms. They constitute the first step towards intellectual mentality, though in themselves do not amount to consciousness...”⁵⁴

⁵¹ Ibid, 251.

⁵² Ibid, 27.

⁵³ Ibid, 253.

⁵⁴ Ibid, 254.

Nevertheless, the application of the Category of Transmutation to even the most rudimentary actual occasions—as is suggested here in its relation to the quantum mechanical decoherence effect—would likely not be objected to by Whitehead, for he explicitly proposes the function of the Category of Transmutation (and the Category of Reversion to be discussed presently) in quantum mechanics; indeed it is this fundamental physical role of transmutation from which higher order mental transmutations ultimately derive:

“The physical theory of the structural flow of energy has to do with the transmission of simple physical feelings from individual actuality to individual actuality. Thus some sort of quantum theory in physics, relevant to the existing type of cosmic order, is to be expected. The physical theory of alternative forms of energy, and of the transformation from one form to another form, ultimately depends upon transmission conditioned by some exemplification of the Categories of Transmutation and Reversion.⁵⁵

“Apart from transmutation our feeble intellectual operations would fail to penetrate into the dominant characteristics of things. We can only understand by discarding... Transmutation is the way in which the actual world is felt as a community, and is so felt in virtue of its prevalent order. For it arises by reason of the analogies between the various members of the prehended nexus, and eliminates their differences...”⁵⁶

Transmutation in Phase III of the concrescence, exemplified in quantum mechanics by the decoherence effect (see the graphic on the last page), results in a reduced density matrix of mutually exclusive, ‘coarse-grained’ subjective forms, each valuated as a probability. Thus, each of the terms in the reduced density matrix,

$$|\alpha|^2 |u_{green}\rangle\langle u_{green}| |d_1\rangle\langle d_1| \text{ and } |\beta|^2 |u_{red}\rangle\langle u_{red}| |d_1\rangle\langle d_1|$$

represents a qualified propositional subjective form or real potential integration of the nexus of facts comprising the system and measuring apparatus, with the excess environmental correlations eliminated, carrying with them the coherent superpositions of incompatible potentia incapable of integration. Again, each subjective form is a qualified potential integration (potential societal nexus) of the system-apparatus facts relative to a particular indexical eventuality (prehending subject), specified by $|d\rangle$, belonging to the measuring apparatus.

Transmutation entails the ‘generic contrast’ of: 1. the real potential serving as the ‘defining characteristic’ by which a given social nexus (‘equivalence class’) is integrated (in our example, the defining characteristic would be $|d_1\rangle$ or $|d_2\rangle$); and 2. the reality of the system of facts ($|\Psi\rangle$) being prehended (related) in the concrescence (measurement). In quantum mechanics, this is exemplified by the contrast of: 1. one of the alternative ‘real potential,’ probable measurement outcome states in the reduced matrix (again, ‘state’ being a maximal specification or form of the facts belonging to a system); and 2. the system of actual, extant facts as data. It is a contrast, in other words, of potential forms with actual facts. This contrast is, once again, mathematically represented as:

$$|\Psi\rangle = \alpha |u_{green}\rangle |d_1\rangle |E_1\rangle + \beta |u_{red}\rangle |d_1\rangle |E_1\rangle$$

⁵⁵ Ibid.

⁵⁶ Ibid, 251.

It is a contrast, in Whitehead's scheme, productive of 'comparative feelings' of which 'physical purposes' are one type:

"The integration of each simple physical feeling with its conceptual counterpart produces in a subsequent phase a physical feeling whose subjective form of re-enaction has gained or lost subjective intensity according to the valuation up, or the valuation down, in the conceptual feeling. This is the phase of physical purpose.⁵⁷

"In the integral comparative feeling the datum is the contrast of the conceptual datum with the reality of the objectified nexus. The physical feeling [or 'Concrete Fact of Relatedness'] is feeling a real fact; the conceptual feeling is valuing an abstract possibility... This synthesis of a pure abstraction [$\alpha |u_{green}\rangle |d_1\rangle |E_1\rangle$ or $\beta |u_{red}\rangle |d_1\rangle |E_1\rangle$] with a real fact [$|\Psi\rangle$], as in feeling, is a generic contrast...

"The constancy of physical purposes explains the persistence of the order of nature... [In a] physical purpose, the datum is the generic contrast between the nexus, felt in the physical feeling, and the eternal object valued in the conceptual feeling. This eternal object is also exemplified as the pattern of the nexus. Thus the conceptual valuation now closes in upon the feeling of the nexus as it stands in the generic contrast, exemplifying the valued eternal object. This valuation accorded to the physical feeling endows the transcendent creativity with the character of aversion, or of aversion. The character of aversion secures the reproduction of the physical feeling, as one element in the objectification of the subject beyond itself. Such reproduction may be thwarted by incompatible objectification derived from other feelings. But a physical feeling, whose valuation produces aversion, is thereby an element with some force of persistence into the future beyond its own subject. It is felt and re-enacted down a route of occasions forming an enduring object...

"When there is aversion, instead of aversion, the transcendent creativity assumes the character that it inhibits, or attenuates, the objectification of that subject in the guise of that feeling. Thus aversion tends to eliminate one possibility by which the subject may itself be objectified in the future. Thus aversions promote stability; and aversions promote change without any indication of the sort of change."⁵⁸

Reproduction, Reversion, and Indeterminacy

In both Whiteheadian metaphysics and the decoherence-based interpretations of quantum mechanics, the classical notion of a 'material body' is taken to be an abstraction from a more fundamental characterization—that of an historical, serial route of actualizations. When probable outcome states or valuated subjective forms are primarily reproductions inherited from antecedent actualizations in the historical route (i.e., when aversion is dominant), the operation of the Category of Conceptual Reproduction is exemplified. Stones and other macroscopic bodies typically perceived as 'enduring objects' are more accurately described as histories dominated by aversion and reproduction—as are statistical ensembles of quantum mechanical measurement outcomes which accord with the same exceedingly high probability amplitudes.

⁵⁷ Ibid, 248-9.

⁵⁸ Ibid, 276-7.

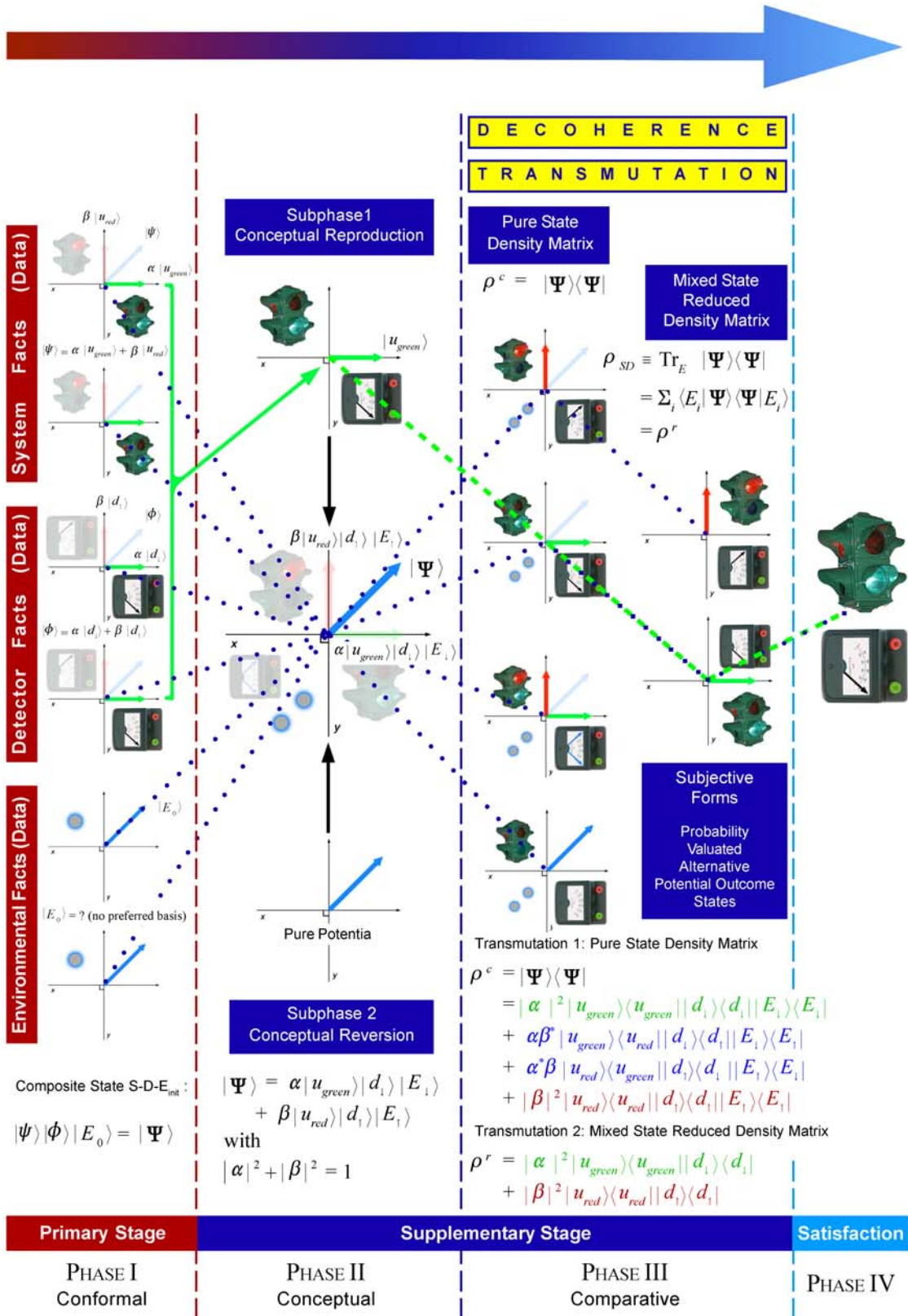
But there are also quantum mechanical processes where reversions are significant—where potential outcome states valuated with a very low probability do nevertheless occur. These might be deemed ‘accidents’ for some systems; and they might be definitive for others (a Scanning Tunneling Microscope [STM], for example, is a device which cannot function apart from such quantum mechanical reversions).

Thus for Whitehead, there are two species of physical purpose: 1. physical purposes due to conceptual reproduction; and 2. physical purposes due to conceptual reversions. A physical purpose of the first species, such as those facts related to the transfer of energy, merely “receives the physical feelings, confirms their valuations according to the ‘order’ of that epoch, and transmits by reason of its own objective immortality. Its own flash of autonomous individual experience is negligible.”⁵⁹ And it is because of “the origination of reversions in the [Supplementary Stage]...that vibration and rhythm have a dominating importance in the physical world”⁶⁰—a concept clearly exemplified by objective quantum indeterminacy.

Any ontological interpretation of quantum mechanics wherein potentia are characterized as a fundamental feature of reality must, at some point, address not only the relationship between these potentia and the actualities from which they evolve, but also the relationship between these potentia and the actualities they evolve to become. One must be concerned with not only what these potential and probable outcome states are in quantum mechanics and from whence they evolved, but also *why* these potential and probable outcome states are what they are. And as Whitehead’s cosmological scheme proposes an answer to many ontological questions commonly raised with respect to quantum mechanics, including those explored in this brief sketch, it attends to this question as well. Whitehead appeals to the three final Categorical Obligations which pertain to the balance of adversion and aversion referred to above—reproduction and reversion—regularity and diversity in the process of concrescence. These are the Category of Subjective Harmony, the Category of Subjective Intensity, and the Category of Freedom and Determination. Whitehead concludes that a tendency toward such balance of adversion and aversion permeates all of nature and is qualitatively manifest as ‘balanced complexity’—and perhaps quantitatively as well, if indeed quantum mechanics is an exemplification of Whitehead’s cosmological scheme. The correlation of the latter with current studies of complex adaptive systems, for example, will be an important avenue of inquiry.

⁵⁹ Ibid, 245.

⁶⁰ Ibid, 277.



References:

- Aspect, A., Dalibard, J. and Roger, G. *Phys. Rev. Lett* 44, (1982):1804-1807
- Bell, John, "On the Einstein Podolsky Rosen Paradox," *Physics*, 1,3 (1964), 195-200.
- Bohm, David, *Phys Rev.* 85 (1952): 166,180. See also: David Bohm, B.J. Hiley, *The Undivided Universe: An Ontological Interpretation of Quantum Theory* (London: Routledge, 1993)
- Born, Max, "Bemerkungen zur statistischen Deutung der Quantenmechanik" in *Werner Heisenberg und die Physik unserer Zeit*, F. Bopp ed. (Braunschweig: F. Vieweg, 1961), 103-118
- Everett, Hugh. "'Relative State' Formulation of Quantum Mechanics." *Rev. Mod. Phys.* 29 (1957): 454-462
- Freedman, S. and Clauser, J. *Phys. Rev. Lett.* 28, (1972): 934-941.
- Geach, P.T. *God and the Soul*, London: Routledge, (1969) 71-72.
- Gell-Mann, Murray, Hartle, James. "Strong Decoherence" *Contribution to the Proceedings of the 4th Drexel Symposium on Quantum Non-Integrability-The Quantum-Classical Correspondence*, Drexel University, September, 1994.
- Gell-Mann, Murray. *The Quark and the Jaguar: Adventures in the Simple and the Complex*. New York: W.H. Freeman and Company, 1994.
- Ghirardi, G. C., Rimini, A., Weber, T.: "Unified dynamics for microscopic and macroscopic systems", *Phys. Rev. D* 34, 470-491 (1986)
- Griffiths, Robert J. *Stat Phys.* 36, 1984, 219. See also, Griffiths, Robert J. *Consistent Quantum Theory*. Cambridge: Cambridge University Press, 2002.
- Heisenberg, Werner. *Physics and Philosophy*. New York: Harper Torchbooks, 1958.
- Lewis, C.S. *The Abolition of Man or Reflections on Education with Special Reference to the Teaching of English in the Upper Forms of Schools*. Macmillan, 1947.
- Omnès, Roland *The Interpretation of Quantum Mechanics*. Princeton: Princeton University Press, 1994.
- Von Neumann, John. *Mathematical Foundations of Quantum Mechanics*. Princeton: Princeton University Press, 1955.
- Whitehead, Alfred North. *Process and Reality: An Essay in Cosmology, Corrected Edition* D. Griffin, D. Sherburne, ed. New York: Free Press, 1978.

Zurek, Wojciech. "Decoherence and the Transition from the Quantum to the Classical" *Physics Today*, 44, 10, 1991, 36.

_____. "Letters" *Physics Today*, 46, 4, 1993, 84.