World Futures, 65: 19–41, 2009

ISSN 0260-4027 print / 1556-1844 online
DOI: 10.1080/02604020802557367

RELATIONAL REALISM: THE EVOLUTION OF ONTOLOGY TO PRAXIOLOGY IN THE PHILOSOPHY OF NATURE

MICHAEL EPPERSON
Center for Philosophy and the Natural Sciences, California State University, Sacramento, California, USA

With the advent of quantum theory, the philosophical distinction between "what appears to be" and "what is reasoned to be" has once again, after several centuries of easy dismissal by classical mechanistic materialism, become an important feature of physics. In recent well-regarded interpretations of quantum physics, including those proposed by Robert Griffiths, Roland Omnès, and Nobel laureate Murray Gell-Mann, we have seen careful investigations into the *physical* (i.e., not "merely philosophical") distinction between *the order of contingent causal relation* and *the order of necessary logical implication*. I argue that a careful philosophical exploration of the function of the logical order in modern interpretations of quantum physics compels the abandonment of derivative classical, dualistic understandings of "determinism *versus* indeterminism," "logical necessity *versus* causal contingency," "subject *versus* object," "epistemic *versus* ontological," among other fundamental dualisms. The incoherence underlying this classical understanding of these principle-pairs as *mutually exclusive* features of reality can be relieved if they are instead understood as *mutually implicative* features of fundamental units of relation or "quantum praxes."

KEYWORDS: Logical causality, praxiology, quantum mechanics, quantum set theory.

The chief mark of progress in the evolution of a worldview, whether its foundation be scientific, humanistic, theistic, or some integration of these, is the extent to which it is able to coherently accommodate diverse categories of inquiry and their associated derivative principles without either arbitrary dispensations or internal contradiction. The precise manner in which a worldview deals with incommensurable fundamental principles and the internal contradictions and paradoxes often borne of them is of first importance, both to the proper understanding of the particular worldview and its implications, and also to its evaluation in contrast to competing worldviews. Indeed, one could argue that the emblematic feature

Address correspondence to Michael Epperson, Director, Center for Philosophy and the Natural Sciences, California State University, Sacramento, 6000 J. Street, Sacramento, CA 95819-6033, USA. E-mail: epperson@csus.edu

of any philosophical genre in the history of Western philosophy, if not all philosophy, is its method of attending to the conceptual incompatibilities within its scope. By that general metric, there have been two dominant approaches by which incommensurable principles—for example, the order of logical implication and the order of causal relation, necessity and contingency, infinite and finite, potential and actual, freedom and determinism, good and evil—have been accommodated in Western thought:

1. Their categorization as fundamentally *mutually implicative* at some deeper and perhaps transcendent level of analysis. By this method of "dipolar" relation it is explicitly recognized that the definition of one principle necessarily requires reference to its counterpart principle. Each relatum constitutive of dipolar conceptual pairs is always contextualized by both the other relatum *and* the relation as a whole, such that neither the relata (the parts) nor the relation (the whole) can be adequately or meaningfully defined apart from their mutual reference. It is impossible, therefore, to conceptualize one principle in a dipolar pair as fundamental to the other.

   Mutually implicative fundamental principles should find their exemplification in both the conceptual and physical features of experience. One cannot, for example, conceive of positive and negative numbers apart from their mutual implication; nor can one define either pole of a magnet without necessary reference to both the other pole and the two poles in relation—that is, the magnet itself. Without this double reference, neither the definiendum nor the definiens relative to the definition of either pole can adequately signify its meaning; neither pole can be defined in complete abstraction from the other.
2. Their categorization as fundamentally *mutually exclusive* at the deepest possible level of analysis. By this method of "bipolar" relation it is implied that the definition of one principle does not necessarily entail reference to its counterpart principle. Therefore it is possible to conceptualize one principle as fundamental to the other.

Clearly, it is the latter method that has dominated Western thought; and despite its variety of schematizations throughout the history of philosophy, the general thesis of mutually exclusive fundamental principles, both ontological and epistemic, has become in the 21st century the defining characteristic of practically every prevailing scientifically informed worldview. One further sees that there have been two general modes by which mutually exclusive fundamental principles have been brought together in relation by this method:

2a. The qualification of mutually exclusive fundamental principles as *complementary* and *irreducible* characteristics of a more general, unified, and necessarily transcendent ontology and epistemology that lies beyond the scope of rational systematization.

As exemplified by modern science, for example, Bohr's principle of complementarity describes the fundamental physical properties of reality in terms of conjugate pairs of properties. Epistemically, these pairs are mutually implicative because they are Fourier transform pairs; thus a more precise specification of "particle position" necessarily entails a less precise specification of "particle momentum." But ontologically, the pairs are mutually exclusive, because a proper and complete conception and definition of "position" does not require reference to the conception or definition of "momentum." Similarly, by complementary wave–particle duality, reference to a particulate model of light is not required for a proper and complete definition and understanding of the wave model of light. Each concept is therefore independent of the other and, in terms of its ontological significance, incommensurable in its complementary relation to its counterpart.

Epistemically, however, this incommensurability is relieved because complementary pairs of relata are mutually implicative in terms of their *qualifications*; again, greater specificity of "position" entails less specificity of "momentum," and so on. But in terms of their *definitions*, they remain mutually exclusive, and thus the problem of ontological incommensurability remains. Bohr's method of relieving this fundamental incoherence was to circumvent it altogether by suggesting that physical qualifications are essentially epistemic—that is, descriptive of our knowledge of reality rather than reality itself. Any ontological implications of these descriptions therefore lie outside the scope of physics. "In physics," Bohr writes, "our problem consists in the co-ordination of our experience of the external world . . . " such that "in our description of nature the purpose is not to disclose the real essence of phenomena but only to track down as far as possible relations between the multifold aspects of our experience" (Bohr 1958, 18).

Thus the coherence of this method of reconciling mutually exclusive principles via complementary relation rests upon the sharp separation of epistemology and ontology, such that a "fact of knowledge" is no longer understood as "knowledge of a fact." Realism, if it is to remain a feature of physics and natural philosophy, is by this method recast as "transcendent realism"—an essential, inaccessible level of reality where mutually exclusive and incommensurable principles find their proper unification.

2b. The qualification of mutually exclusive fundamental principles as higher order characteristics or modes of a deeper, fundamental ontology and epistemology that can be further generalized by the reduction or assimilation of one characteristic to the other.

The history of philosophy reveals a clear tendency toward this method; indeed, one could argue that its dominance in philosophy—particularly philosophy of nature in the early modern period—was the primary fuel for its dominance in modern science and, via the latter, its increasing popularity in most modern Western worldviews. One can find its origins in much of pre-Socratic philosophy, perhaps most notably in the Eleatic School. As an admonishment against the relation of actuality and potentiality as mutually exclusive, fundamental principles of reality, for example, Parmenides gave a convincing argument for the reduction of potentiality to actuality: Anything that "can be," he asserted, "must already be." There can be no "coming into being" because anything that comes into being has only two possible derivations: It either came *from* being, in which case it already exists; or it came from non-being, or "nothing," in which case it, too, is nothing, because nothing comes from nothing. Indeed, one cannot even imagine a "potential" actuality that was not already actual, because imagining something that did not actually exist would literally amount to imagining "no thing," and thinking about nothing, Parmenides argues, is the same as not thinking.

Because "potentiality" is therefore merely a sensory-epistemic abstraction from fundamental actuality, existence is therefore both eternal and unchanging—the Parmenidean "One"; any perceived differentiation is only apparently real as disclosed via sensation, not actually real as disclosed by reason. Although this lay the groundwork for Platonic idealism as another type of philosophical reduction from mutually exclusive fundamental principles—ideal/thought/form versus material/sensation/extension—it is important to note that Parmenides was not an idealist, but rather a monistic materialist. Thus one can find in many modern physical theories a number of Parmenidean reflections: Everett's Relative State Interpretation (Everett 1957, 454–462) of quantum mechanics (better known as the "many worlds" interpretation) makes a similar assimilation of potentiality to actuality, such that every possibility is properly understood as an actuality in some particular universe. But the division of reality into multiple, mutually exclusive universes is understood in many interpretations of the theory as a higher order abstraction beneath which lies a first order, unified multiverse concept—in many ways akin to the Parmenidean "One."

Similarly, the Bohm-Hiley non-local hidden variables interpretation of quantum mechanics (Bohm 1952, 1986; Bohm and Hiley 1993) describes the universe as epistemically divisible but ontologically undivided. Quantum physics as an epistemic enterprise glimpses this ontological unity via its fundamental characterization of the universe as an "implicate order" of actualizations of potentia—which would at first seem to disagree with the Parmenidean worldview. But in the Bohm-Hiley interpretation, past and future are symmetrically related, and therefore ontologically indistinguishable; any potential "coming to be" in the future is already contained in what already exists and existed. Past, present, and future, although epistemically distinct within the context of our finite observational structures, are nevertheless ontologically unified in a quasi-Parmenidean "One."

Bohm writes:

> If it were possible for consciousness somehow to reach a very deep level, for example, that of pre-space or beyond, then all "nows" would not only be similar—they would all be one and essentially the same. One could say that in its inward depths now is eternity. . . . (But eternity means the depths of the implicate order, not the whole of the successive moments of time.) (Bohm 1986, 199)

Further, for Parmenides, the reduction of potentiality to actuality implied related reductions of other mutually exclusive principle-pairs, such as creativity versus discovery. As noted earlier, in Parmenidean philosophy every "imagining" is ontologically reducible to thinking about existence. And similarly, within the depths of the veiled implicate order underlying the Bohm-Hiley undivided universe, all potentia are ontologically reducible to actuality; all apparent creativity is ontologically reducible to discovery. The ground of any experience *interpreted* as creativity (instead of *understood* as discovery) is the epistemic restriction or contextualization of all experience within our necessarily finite observational structures.

Bohm writes:

> As long as we restrict ourselves to some finite structures of this kind, however extended and deep they may be, then there is no question of complete determinism. Each context has a certain ambiguity, which may, in part, be removed by combination with and inclusion within other contexts. [...] If we were to remove all ambiguity and uncertainty, however, creativity would no longer be possible. (Bohm 1986, 198)

The success of the method of reduction and assimilation in science, at least as measured by the apparent ability to predict and control nature yielded by this method, has inevitably led to a host of physics-inspired philosophical and cosmological reductions such as those discussed earlier. The philosophical cosmologies borne of the "many worlds" and "implicate order" interpretations of quantum mechanics are just two of many modern examples of reductive philosophical cosmologies inspired by and grounded in scientific reductionism. Indeed, for the scientific-dominant worldviews in general, the thesis of fundamental mutually exclusive principles, and their attempted interrelation via either of the two modes described earlier, has today become their defining characteristic. The following pairings can, for example, be considered respectively: classical mechanics versus quantum mechanics; quantum mechanics versus general relativity; wave–particle dualism; local versus nonlocal causality; actuality versus potentiality; finite versus infinite; determinism versus indeterminism.

Similarly, in the theistic-dominant worldviews, the thesis of mutually exclusive fundamental principles is exemplified in other interrelated pairings, including: good versus evil; determinism versus freedom; necessity versus contingency; perfection versus imperfection; permanence versus change; heteronomy versus autonomy; and perhaps most infamously today, the concept of cosmogonic "creation" versus the concept of cosmological "evolution." Even an unstudied understanding of the latter conceptual pair, with its unfortunate domination of current conversations between science and religion, reveals that the primary fuel by which this relationship is sparked into conflict is the stubborn characterization of "creation" and "evolution" as mutually exclusive concepts whose only proper mode of coherent relation is the reduction or assimilation of one concept to the other. By contrast, religious traditions that view creation and evolution as mutually implicative—for example as initiation and becoming—generally see no conflict whatever between science and religion; indeed, for these traditions, science and religion are themselves seen as mutually implicative features of a common worldview.

Worldviews for which neither science nor religion are seen as foundational might simply be termed "humanistic," where fundamental mutually exclusive principles are housed, in the most general sense, within the dualism of subjectivity and objectivity. This pairing has its more specific application within a variety of disciplines in the humanities: In literature, deconstruction versus intentionalism; in philosophy, mind versus matter; thought versus extension; the order of logical implication versus the order of causal relation; necessity versus contingency, permanence versus change, unity versus diversity, and so on.

In all of these examples, one can find within the history of Western thought a wide variety of systematic attempts to bridge fundamental mutually exclusive conceptual relata by way of either the method of complementarity in the context of transcendent realism (Method 2A above) or by reduction and assimilation (Method 2B). In the early modern period, the overly general division of philosophy into the rationalist versus empiricist traditions, each with deep roots in classical philosophy, well reflects the popularity of the method of reduction and assimilation. A careful survey of these philosophical schemes falls outside the scope of this article, but readers familiar with the history of philosophy will be able to experiment with the two aforementioned classifications; for example, Spinoza attempted to assimilate the causal order to the logical order, the contingent to the necessary; Locke attempted to assimilate the logical order to the causal order—both examples of Method 2B. Kant's Transcendental Philosophy can likewise be seen as an example of Method 2A, the method of transcendent realism (i.e., in the sense of his transcendental idealism, by which "things in themselves" transcend the understanding.) Fundamental complementarity, within this context, is evinced throughout his system—his discussion of "conditioned" and "unconditioned" knowledge in the Transcendental Dialectic, for example.

The chief deficiency of the categorization of incommensurable principles as fundamentally mutually exclusive at the "deepest possible" level of analysis is its presumption that the bounds of reason have been reached. Fundamental complementarity marks this boundary in Method 2A, where the problem of mutually exclusive foundational principles is relieved only by reference to some ineffable, transcendent unification or implicate order that lies on the other side of the boundary, beneath the veil of finite observational contexts or, even worse, beyond the supposed scope of reason itself. But this merely exchanges one incoherence for another: the incoherence of incommensurable first principles is traded for the incoherence of qualifying the "unknowable" as unknowable, via the reasoning of the unreasonable—or, in modern science, the "scientific" hypothesizing of the unfalsifiable. The various multiverse and string theory cosmologies exemplify this method and its deficiency when spread from philosophy into science.

Method 2B is equally problematic—the attempted reduction or assimilation of mutually exclusive fundamental relata, one to the other, so that one is re-defined as concrete and the other abstract—one ontologically significant, the other an epistemic artifact. Again, the method of reduction and assimilation rightly recognizes the need to bring into coherence mutually exclusive, incommensurable first principles; but it wrongly grasps for that coherence by arbitrarily restricting the speculative schematization of the experience of nature to certain preferred categories of thought, in exclusion of other categories that could just as reasonably be characterized as fundamental. By this method, nature is always *either* fundamentally physical *or* fundamentally conceptual; either fundamentally continuous or fundamentally quantum; either fundamentally finite or infinite; either fundamentally determinate or indeterminate. When one considers the increasingly profuse inflations of physical cosmological models into metaphysical cosmologies, their practically stipulated significance is belied by the fact that one can casually assemble practically any combination of the aforementioned qualifications and find a correlate interpretation of quantum theory or string theory or some other physical cosmology that can accommodate it.

At the level of fundamental principles, the method of purely reductive science breaks down. The reason is because theorists enamored of this method fail to recognize the ineluctable possibility of deeper levels of abstraction underlying any "ultimately reduced" principle qualified as "fundamentally concrete" by this method. It is a conceptual hazard that Whitehead famously termed the "fallacy of misplaced concreteness," and its pertinence to modern science has never been more important—especially for those worldviews that, in their ongoing construction, use science as bedrock, framework, and scaffold. The target height of construction is nothing less than the "explanation of the universe" via sheer reduction. This bounding leap from "fundamental scientific description of the universe" to "fundamental scientific explanation of the universe" is one that has perhaps been less careful than such a leap would warrant. And likewise, these increasingly routine leaps typically receive little critical attention despite the obvious logical obstacles that belie the reasonableness of even attempting such a leap.

One might consider, for example, the growing number of philosophically and even theologically loaded discussions of various physical cosmologies, introduced for public consideration via media such as the popular book market, PBS series, and even the opinion-editorial pages of major newspapers. The tacit stipulation of many such presentations is that the demonstrable ability of the scientific method to construct sound reductionist descriptions of nature *in itself* warrants its broader application to the task of explaining or "accounting for" nature at the most fundamental level. What is neglected in this metaphysical misapplication of the scientific method is the fact that a "fundamental explanation" (i.e., "complete explanation") constructed via the method of deduction, such as that instantiated in the hypothetico-deductive scientific method, is impossible. This is because the first principles of any deductive chain of reasoning are always necessarily presupposed. Science, for example, cannot "explain" the logical order—that is, account for its origins—because the language and methodology of science necessarily presuppose this order.

In their 1983 paper "The Wave Function of the Universe," for example, Stephen Hawking and James Hartle propose a quantum mechanical explanation of the origin of the universe whereby the universe spontaneously creates itself *ex nihilo* as a quantum mechanical probability function. Hawking later clarifies the theological implications of this model by stating that it allows for the elimination of the notion of God in the explanation of the origin of the universe (Weber 1986, 212).

What is neglected by both this model and its characterization by Hawking is the fact that quantum mechanics presupposes a logical order by which the potentia integrated by the mechanics are reduced into mutually exclusive and exhaustive (i.e., logically coherent) probability outcomes. But more than just presupposing a logical order, quantum mechanics presupposes a correlation of this logical order with *some* causal order of actualities from which the potentia derive. Quantum mechanics begins with actualities, in other words, not simply "bare potentialities."

Assigning the name "quantum vacuum" or "quantum foam" to this background belies the fact that this background is both actual and logically ordered, such that the causal relations of this background are describable in the language of logical implication (e.g., via quantum mechanics). Therefore the quantum mechanical cosmogony offered by Hawking and Hartle cannot be properly described as *ex nihilo*, and therefore "random." (Indeed, even "randomness" as a mathematical coordination presupposes an underlying logical order.)

Any deductive chain of reasoning, including the modern scientific method of hypothetical deduction, must begin with first principles that are explicitly presupposed and therefore incapable of explanation via deduction alone. Thus, again, science cannot "explain" the logical order—that is, account for its origins—since the language and methodology of science necessarily presuppose this order. In the aforementioned example, quantum mechanical cosmological models clearly offer valuable fundamental descriptions of the earliest stages of the evolution of the universe; but the model's failure to account for the logical order constitutes failure to "scientifically explain" the origin of the universe in the fundamental sense of "explanation" that Hawking clearly intended.

Whitehead's fallacy of misplaced concreteness, when applied to these increasingly popular inflations of physical cosmology to philosophical cosmology—the various quantum, string theory, and multiverse cosmologies being just a few of the more recent examples—is crucial because it reminds us that science can never explain away that which it necessarily presupposes. The logical order underlying mathematics can never be deductively explained or reductively accounted for by a scientific description of the causal order, because the logical order is necessarily presupposed by the method of scientific description. Fundamental reductionist scientific descriptions of nature can never attain the status of fundamental explanation, because there is always a deeper level of abstraction underlying any deductive or reductive scheme, scientific or otherwise.

One of the earliest and clearest illuminations of the deficiency of this method when applied to the task of "fundamental" or "complete" explanation can be found in Plato's *Theaetetus*. There Plato challenges the idea that a sufficiently deep reduction can serve as a sturdy bridge across the chasm separating description and explanation—appearance and reality. 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—that is, 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, necessary, and unfortunately, unknowable. How, asks Socrates, can the unknowable be the foundation and ultimate justification of knowledge?

One sees this well reflected in Gödel's first incompleteness theorem, Theorem VI, which states that no theory capable of expression in the language of arithmetic can ever be both internally consistent *and* complete. Any effectively generated formal theory that is (1) internally consistent and (2) allows for the deduction of arithmetical proofs, will always presuppose some arithmetical statement that is both true and incapable of proof by the theory. As it pertains to the relationship between the order of causal relation and the order of logical implication, for example, one might consider the various self-referential paradoxes often associated with Gödel's theorem, such as the Epimenides paradox; and in the context of the problem of mutually exclusive first principles, this relation is useful. The Epimenides paradox is given in the ancient Cretan philosopher's infamous utterance: Κρῆτες αεί ψεύσται ("Cretans, always liars.") The statement implies both a causal order and a logical order, and the statement can be neither true nor false without internal contradiction—a problem reflective of a fundamental incoherence in the treatment of causal relation and logical implication as mutually exclusive principles by which we attempt to order our experiences of nature.

By the end of the early modern period, during which the foundations of the modern scientific method were forged, the order of causal relation and the order of logical implication—that is, contingency and necessity, and other associated bipolar conceptual pairings—were generally treated by natural philosophers as mutually exclusive concepts. The various proposals for their coherent relation generally entailed either their treatment as complementary epistemic features and co-ordinations of our experiences of an otherwise transcendent reality; or as second-order epistemic concepts that can be distilled into a single first-order principle via the reduction or assimilation of one concept to the other. Whether continental rationalist or British empiricist, the common goal was to bridge the two sides of the Platonic chasm (χωρισμος) separating "what appears to be" from "what is reasoned to be." Despite the richness of detail to be found in the various philosophical systems proposed during this period, the tendency toward the method of mutually exclusive relation of the causal and logical orders, and contingency and necessity respectively, resulted in two basic mappings across Plato's chasm:

1. appearance: sensory perception of contingency via causal relation
   reality: rational conception of necessity via logical implication

2. reality: sensory perception of contingency via causal relation
   appearance: rational conception of necessity via logical implication

It is clear that both of these mappings *together* have been inherited by most modern, scientifically informed worldviews, and the unavoidable incoherence generated by the attempted embrace of both mappings at once has proven to be a major impediment to the evolution of philosophically informed science in general. One sees the difficulty, for example, in the distinction between "theoretical physics" versus "experimental physics," and the fact that this distinction has become a matter of convention. Theoretical physics, when applied to the "external" foundational questions, that is, philosophically loaded cosmologies that purport to "explain" the origin of the universe rather than merely describe its evolution, implies the reduction of the world to bare mathematics—the reduction of all contingency to necessity. Experimental physics, when applied via disciplines such as molecular biology and neurophysiology to "internal" foundational questions, for example, the relationship of mind to brain, of conception to perception, of "personality" to the physical structure of DNA, likewise implies a "purely physical" causal closure—a purportedly explicative reduction of the world (against the Platonic admonition in the *Theaetetus*) to fundamental particles and their energies.

One example of the net effect of this incoherence on modern, scientifically informed worldviews is the fundamentally incoherent, conflicted self-characterization of the human person. "I am a body" and "I have a body" are two incompatible notions of self that many attempt to hold at once within the context of a scientifically informed worldview. This internal conflictedness manifests itself in a wide array of external conflictedness—for example, the attempt to reduce biology to theology via "scientifically grounded" enterprises such as "creation science" or "intelligent design"; or the converse attempt to reduce theology to biology via the reduction of spirituality to epiphenomena via psychology and neurophysiology (cf., for example, Alper 2006).

Even a cursory survey of the philosophy of science reveals that its long history of efforts to both characterize the causal and logical orders as mutually exclusive foundational concepts, and at the same time coherently bridge these concepts and their associated conceptual pairings—contingency and necessity, finite and infinite, actuality and potentiality—by either complementary relation, or reduction and assimilation of one to the other, have failed. The method of complementary relation is, by its own admitted limitations, incapable of yielding anything more than an arbitrary explanation of either the logical or causal orders as complementary epistemic co-ordinations of our experiences of an ontologically transcendent reality; and the method of ontological reduction and assimilation, when it reaches the level of fundamental explanation, is doomed by the fallacy of misplaced concreteness—first given by Plato and more recently rehabilitated in the work Gödel and the philosophy of Whitehead.

Plato's argument in the *Theaetetus* and its mathematical exploration in Gödel's Theorem VI, suggests that the incoherence of relating incommensurable first principles as mutually exclusive can be relieved, simply, by treating such principles instead as mutually implicative within some presupposed unifying context. The paradoxes are relieved, in other words, when one ceases to consider each principle individually and instead considers them in definitive relation to one another within the context of a presupposed, underlying unity. This unifying context is necessarily presupposed because, as Gödel demonstrated, it cannot be "accounted for" solely by reference to the individual principles united. This underlying context can be *rationally* presupposed, because the principles are, in fact, definitively self-referential; the question is simply whether or not one desires that this self-reference be incoherent or coherent; and because coherence is a definitive feature of reason itself and an explicit desideratum of the enterprise of logic, the presupposition of a context that provides such coherence is entirely reasonable. It is not demonstrable or provable via reduction or deduction; but this is no more problematic than the equally speculative tacit presupposition of a logical order by the enterprise of science itself. It is only when science attempts to account for this order while at the same time presupposing it that scientific reason confronts itself with incoherence and paradox.

Thus, the method of relation of fundamental cosmological principles, both physical and metaphysical, by mutual implication requires a philosophical method that transcends the typical restrictions of philosophical deduction and induction and demonstration—especially as historically coupled with the hypothetico-deductive method of modern science. The method of "speculative philosophy" discussed at the beginning of *Process and Reality* (Whitehead 1978, 3–17), Whitehead's epic essay on systematic cosmology, is a clear example of such a method, whereby the presupposed context by which fundamental principles find their mutual implication is not derivable by simple deduction or logical demonstration. Rather, it is the product of imaginative generalization, continuously tested and refined against experience according to the coupled desiderata of coherence and empirical adequacy. There is thus never any final arrival at or demonstration of that presupposed context; but nor is there an arbitrary claim that this context is wholly transcendent and cannot even be aimed at in the first place (per, for example, the complementarity-based schemes grounded in transcendent realism). There is instead an asymptotic approach to the presupposed, unifying context, such that progress is always both measurable and, at the same time, unending.

Process and Reality itself is a clear (and for many, unsurpassed) example of a robust, thoroughly systematized cosmology built upon a foundation of mutually implicative first principles via the method of speculative philosophy. For Whitehead, the underlying context by which the causal and logical orders are united in dipolar fashion, via mutual implication, is the dipolar "actual occasion" or "final real thing"—the imaginatively generalized fundamental unit of reality. But rather than being *solely* a unit of being, which would expose the actual occasion to the argument of Parmenides, it is also, and more fundamentally, a unit of becoming—a unit of process, or actualization, that entails both a causal-physical pole and a logical-conceptual pole; and each pole is mutually implied within the contextual unity of the actual occasion as a whole. When actualized, the occasion has its causal efficacy on subsequent actualizations; and likewise, its process of actualization is affected by both (1) its causal physical relations with the actualities "physically" prior to it in terms of spatiotemporal extensiveness—that is, within its backward lightcone, per the restrictions of relativity theory and (2) its logical relations with those actualities "logically" prior to it, per the restrictions of the Principle of Non-Contradiction, among other logical restrictions.

Each actual occasion is thus fundamentally a *unit of relation*. In the process of actualization, the becoming occasion is internally related to its dative world of antecedently actualized occasions, and these relations are both causally and logically ordered: because the actualization is internally related to its dative world, it is a unit of relation wherein the relation is an integration of potentia datively provided by the world. (Thus, another philosophically problematic conceptual pair, "unity" and "diversity" are also brought into coherence via mutual implication. "The many," writes Whitehead, "become one, and are increased by one. In their natures, entities are disjunctively 'many' in process of passage into conjunctive unity" (Whitehead 1978, 21)). These integrations are always logically governed, such that upon actualization, the occasion is related to the world in a manner free of violations of the Principle of Non-Contradiction, or any other such violation of the logical order. Writ large, the universe is thus described as a networked system of serial routes of actual occasions; the integrative internal relations of every actualization constitutive of each route are logically governed such that the orders of causal relation and logical implication are correlated (again, this is a speculative presupposition grounded in the concept of the dipolar actual occasion). Relations between routes also evince this correlation—even those that are spacelike separated and incapable of causal physical ordering—that is, ordering within a 4D spatiotemporal extensive framework, which modern physics employs for the analysis of macroscopic systems.

It is by the physical and logical dipolarity of the actual occasion in relation to its dative world that the inability to *physically* or *causally* order spacelike separated occasions per the restrictions of relativistic 4D space–time does not in any way imply that these spacelike separated occasions similarly lack a logical order. By the dipolar concept of the actual occasion, the inability of physics to specify a physical-causal order among spacelike separated occasions does not negate the necessary presupposition of a logical ordering of these occasions *if* it is a speculative desideratum that the causal and logical orders be coherently related by mutual implication. It is a necessary presupposition because such a negation would imply that logic is neither invariant nor universal—that it is, like physical spatiotemporal extension, merely locally specifiable. It must be remembered that this ordering and the logical coherence it exemplifies within the cosmology is merely a presupposed desideratum. It is not reducible via deduction or scientific demonstration because the logical order is a necessary presupposition of deduction and scientific demonstration. The dipolar actual occasion as a fundamental unit of causal and logical relation is likewise the presupposed context, inspired by the Platonic argument in the *Theaetetus* and rehabilitated in Gödel's incompleteness theorem, by which the causal and logical orders are coherently related by mutual implication.

The utility of Whitehead's speculative philosophical scheme is perhaps best evinced by its application to the task of coherently interpreting scientific theories that are conventionally accepted as fundamental, yet are nevertheless profoundly resistant to coherent integration. The integration of quantum theory and general relativity is a particularly problematic example given the ever-increasing application of each theory to fundamental cosmological and even cosmogonic questions. The centuries old physico-reductive, mechanistic-materialistic approaches to relating by division the causal and logical orders as mutually exclusive features of reality laid the groundwork for the string theoretical, multiverse, and quantum cosmologies discussed earlier in this article. Likewise, a speculative philosophical relation of the causal and logical orders as mutually implicative fundamental features of reality lays the groundwork for an alternative and arguably improved systematic cosmology, as robustly informed and confirmed by modern physics as the mechanistic-materialistic approach—but without the underlying conceptual incoherence.

With the advent of quantum theory, the philosophical distinction between "what appears to be" and "what is reasoned to be" has once again, after several centuries of easy dismissal by classical mechanistic materialism, become an important feature of physics. In recent well-regarded interpretations of quantum physics, including those proposed by Robert Griffiths, Roland Omnès, and Nobel laureate Murray Gell-Mann, we have seen careful investigations into the *physical* (i.e., not "merely philosophical") distinction between the order of contingent causal relation and the order of necessary logical implication. Each of these interpretations, in its own way, makes an explicit appeal to the logical order as somehow "physically efficacious" in or "governing of" processes such as decoherence and non-local, EPR- (Einstein, Podolsky, and Rosen) type quantum mechanical measurement interactions, among many other associated quantum processes.

The familiar classical conceptions of "subject," "object," "epistemology," and "ontology" find no fully coherent mapping onto these recent advances in quantum physics, apart from their casual, practical application. In the same way that the causal and logical orders are treated as mutually implicative in these modern interpretations of quantum physics, so too are the pairings of "subject and object," "epistemology and ontology."

A careful philosophical exploration of the function of the logical order in modern interpretations of quantum physics yields an ineluctable re-casting of the classical, dualistic understandings of "subject-object" and "epistemic-ontological": The "subjective" and "objective" features of nature described by quantum physics are, by this re-casting, *not* best seen as fundamental, complementary, mutually exclusive features of reality as suggested by Bohr; rather, they are more coherently understood as mutually implicative features of fundamental quantum units of relation (Epperson 2004). The Aristotelian *infimae species* are not material quanta related as "subject" and "object"; the *infimae species* are, rather, the quantum relation-events, or "quantum praxes" themselves, and their logical ordering into serial quantum histories (cf., for example, Griffiths 1984, 219–272 and Griffiths 2002).

Whereas quantum physics was initially lamented for the intrusion of "subjectivity" into "objective" physics, the explicit accounting of the role of the logical order in quantum physics reveals that it is not fundamental subjectivity that is evinced, but rather fundamental relativity, whose ultimate physical units are quantum praxis-events and their serial, logically ordered histories.

Problematic phenomena such as EPR-like, nonlocal quantum causality can be more coherently accounted for in such a historico-holistic relational framework, and not merely tolerated as an odd dispensation from classical, local causal mechanics. But at the same time, classical, local mechanics are not merely dismissed or "explained away" as epistemic artifacts of an underlying, fundamentally holistic quantum ontology such as that proposed by Bohm and Hiley, for the universe is not "sheerly" holistic by this interpretation of quantum physics, which further leaves space for both epistemological and ontological emergence—that is, genuine novelty.

The speculative philosophy of "relational realism" I propose herein, with its "quantum praxiological" interpretation of the quantum theory, depicts the local and nonlocal features of these quantum relation-events or quantum praxes as mutually implicative features of reality. Causal relations that are locally restricted by their respective light cones and the constancy of the speed of light are, nevertheless, governed by their associated logical relations, which are not locally restricted by *c* (consistent with Einstein's special and general theories of relativity.) Thus, nonlocal EPR-type experimental results can be properly understood not as "nonlocal causality at a distance" via some superluminal transfer of energy in violation of classical mechanics (as given in the various hidden variables interpretations, for example), but rather as causal quantum mechanical relations among spatially well-separated but logically ordered quantum praxes.

Within the past few decades, a confluence of key scientific and technological developments has set the stage for an historic rehabilitation of speculative, scientifically informed metaphysics; and it is this rehabilitation that will, as applied to the ongoing evolution of modern, intellectually informed worldviews, most likely provide the most sure-footed pathway connecting the houses of science, philosophy, and theology. It is hoped that the relational realist integration of speculative metaphysics and modern science, particularly as instantiated in a praxiological interpretation of quantum physics, might lead to promising new strategies for forging substantive advances in at least four primary areas: (1) Reductionism, determinism, and causal closure; (2) The mind-body problem; (3) The "hard" problem of consciousness; and (4) The relationship between quantum indeterminacy and free will.

To this end, my colleague David Finkelstein at the Georgia Institute of Technology and senior research fellow with me at the Center for Philosophy and the Natural Sciences (CPNS) has proposed new insights into quantum physics that characterize classical logic as merely a singular limit of quantum kinematics, and an emphasis of "actions" (praxes) versus "objects." Similarly, my colleague and senior CPNS research fellow Henry Stapp at the Lawrence Berkeley National Laboratory has studied the ways in which large, complex systems such as the human mind exemplify these mutually implicative concepts—subject/object, logical/causal, epistemic/ontological—and their underlying quantum physical formalism. Stapp's theoretical work on "quantum neuroscience," for example, applies an effect of well-tested standard quantum theory (the quantum Zeno effect) to obtain testable predictions about how the body can act in accord with the conscious intent of a human observer.

The goal here, as an experimental exploration of the philosophy of relational realism, will be to identify ways in which the metaphysical principles undergirding our proposed non-materialistic, non-dualistic, "event-ontological" ("praxiological") interpretation of quantum physics might be exemplified in modern neuroscience and other important applications. It is important to note here, however, that a neuroscientific *exemplification* of the quantum theoretical framework in no way implies a *reduction* of mind or consciousness to quantum mechanics. As a metaphysical desideratum, it is expected that logical causality, as the *a priori* foundation of a "reasonable" universe, will have its reflection in the functioning of the "reasoning" human brain. If quantum physics can be shown to be demonstrably applicable to a neuroscientific description of the brain—even in a limited sense—then it could be argued that the key role of the logical order in our approach to interpreting quantum mechanics will be reflected in the logic underlying human reason.

The coherent correlation, in the language of physics, of the causal and logical orders—one that includes a careful distinction between causal (i.e., efficient causal) efficacy and "logical efficacy" or "logical governance"—is of first importance in modern physics, and in modern science and philosophy more generally. Such a correlation might ultimately reveal deeper levels of systematic distinctiveness among the manifold competing modern interpretations of quantum physics—distinctiveness that is at once metaphysical and demonstrably physical. More broadly, the relational realist philosophy is intended to exemplify a novel double-rapprochement of physics and metaphysics that could advance an understanding of nature in ways that transcend the conventional separation of these two disciplines. Perhaps most important, the approach of relational realism proposes a novel means of bridging the centuries-long proliferation of disconnected worldviews by which "science" is variously interpreted as exemplifying mutually antithetical "ultimate" meanings and cosmological implications—reductionism versus holism, objectivism versus subjectivism, cosmogonic creation versus cosmological evolution, among many others. This proliferation has markedly impeded progress toward the evolution of scientifically informed worldviews capable of coherently accommodating fundamental features of experience that lie beyond the restricted scope of scientific description.

The primacy of modern science in the formation of most of today's self-characterized "modern realist" worldviews has been powered primarily by two vital engines that have carried Western philosophy of nature to eminence into the 21st century. The first engine, technological innovation, is often mistaken as the "primary" engine driving this ascent because its roar has, over the centuries, generated the most attention; but its less-regarded twin engine of mechanistic-substance metaphysics has contributed equally to the overall momentum. And indeed, throughout the history of the philosophy of science it is clear that a major function of each engine has been to carry the weight of the other. And with occasional adjustments of balance and attunement over the past four centuries, mechanistic-materialism has contributed steadily and surely to the rise of modern science and philosophy.

With the advent of quantum mechanics early in the 20th century, however, the engine of mechanistic-materialism has begun to sputter noticeably. In just the past few decades, classical philosophy of nature, with its comfortably understood bipolar foundational concepts—"ontology versus epistemology," "objectivity versus subjectivity"—has fallen so far out of alignment with the engine of technological innovation that the wobbling can no longer be ignored. Superconducting quantum interference devices, experimental demonstrations of quantum nonlocality, quantum transistor technology. . . . These and other innovations have not been so easily borne by mechanistic-materialism as were the classical technological innovations of centuries past.

Even so, the desire to keep classical mechanistic-materialism in service has easily trumped most efforts to modernize, perhaps because its coming of age back in the 17th century was such a triumph; for beyond the technological innovations it helped to power, mechanistic materialism was the first technologically proven bridging of the Platonic chasm that had dominated philosophy for over 2000 years—the chasm separating description and explanation of phenomena—"what appears to be" and "what is reasoned to be." With classical science, a seemingly secure pathway from appearance to truth, from contingency to necessity, had finally been discovered; for proof, one needed to look no further than the technological breakthroughs fostered by this science, and the scientific breakthroughs that would, in turn, result from these new technologies.

David Hume was perhaps the last empiricist of the early modern period to warn that cyclical progress of this kind, no matter how exhilarating, was no proof of crossing the Platonic chasm—that even the most careful empiricism could never demonstrate a real bridging of the orders of necessary logical implication and contingent causal relation. The mathematical and philosophical first principles associated with the logical order could, Hume argued, never be found within fundamental, ultra-reductive physical descriptions of phenomena associated with the causal order. The certainty of an objective logical conception such as "if p then q" can neither be deduced from nor demonstrated by a subjective causal perception such as "p (seemingly) causes q." Logical necessity can never be soundly derived from causal contingency, no matter how carefully, or to whatever reductive depth, the latter is measured.

Despite such admonitions from Hume and others, the twin engines of modern technology and mechanistic-materialism pushed forward steadily and unimpeded well into the 20th century, carrying with them what have become today's conventional, modern-realist, bipolar conceptions of "subject vs. object," "epistemology vs. ontology," "logical implication vs. causal relation," "conceptual vs. physical"... But after several decades of attempts to map these concepts onto quantum physics in a manner consistent with their familiar mapping onto classical physics, the old, steady trajectory of classical, reductive empiricism, borne by the heretofore well-proven engines of technological innovation and mechanistic-materialism, has slowly begun to degenerate. The drive toward a confident crossing of the Platonic chasm via the route of sheer reductionism applied to mutually exclusive first principles of experience—unification of the sciences via scientism—has, since the advent of quantum mechanics, instead degenerated into a divergence of barely paved "interpretations" of quantum physics, with no easy metric by which these ever-branching routes to truth might be evaluated. Indeed, "The Truth" as science's final goal is no longer the clear destination it once had seemed to be. The chasm separating fundamental descriptions of nature and fundamental explanations of nature remains unbridged. The familiar classical conceptions of "subject," "object, " "epistemology," and "ontology"—the conventionally accepted foundations for all reasonable attempts at construction—simply have not been able to bear the weight of the new physics.

The notorious "problem of measurement" in quantum mechanics is perhaps the best exemplification of the difficulty in two key respects:

1. Quantum theoretical descriptions of the "measurement" of "objects" by "subjects" always yields a linear superposition of possible objective states; yet the actual measurement interaction always terminates with a unique "measured object" in a definite state. Thus the logical principles of Non-Contradiction (PNC) and the Excluded Middle (PEM) are *always satisfied* in the practice of quantum mechanics; yet they are not in any way *accounted for* by the quantum theory itself.
2. The classical separation of "subject" and "object" and the associated separation of "epistemology" and "ontology" are, at best, only clumsily applicable to quantum physics. "Objective" states are not only *subsequent* to measurement by (i.e., active relation with) a "subject" but *consequent* of such active relation—integrally *part of* measurement interaction—a seeming intrusion of subjectivity into the classical conception of physical objectivity. And worse still for classical mechanistic-materialism, the "subject" appears to play some *physical* role in qualifying possible outcome determinations, because these possible "objective" qualifications are always expressed in terms of subjectively derived qualifications of the measurement interaction.

Thus every classically conceived "object" and "subject" is, by the light of quantum mechanics, more fundamentally described as a chain of quantum "measurement interactions" or, more generally, "quantum praxes." By this description, the classical dualistic separation of subject and object is rendered a conceptual abstraction—as is the correlate classical bipolar dualistic separation of ontology and epistemology. If the fundamental constituents of nature are more accurately describable as "quantum praxes," from which we might abstract the classical conception of "objects known by subjects," we can similarly characterize the classical conceptions of ontology and epistemology as conceptual abstractions from a more fundamental quantum praxiology. In the context of the latter, epistemology and ontology are understood as mutually implicative dipolar aspects of every quantum praxiological unit of relation—every praxiological "final real thing."

The term "praxiology" (and its alternative spelling, "praxeology") has traditionally referred to the study of human action, as rooted in the work of French philosopher and sociologist Alfred Espinas (1844–1922). Recent scholarship by the French and Polish academies, however, has traced the origins of praxiology to the work of philosopher of science Louis Bourdeau, who coined the term "praxeologie," defining it as a "science of functions" (Bordeau, 1882, v2). The application of the term "praxiology" to quantum physics, particularly with respect to the work of von Neumann and the implications described earlier, exemplifies several of Bourdeau's key conceptions of praxiology as "the science of functions." For example, Bourdeau writes:

> We give the name of "function" (from the Latin *fungor*, 'I perform') to a series of effects which are accomplished in a certain form under the influence of actions of the environment. . . . Expressing the relationship between forms and the environment, it matches the condition of the former to those of the latter and relates

> each being to its habitat. Hence, it connects the parts to the whole, subordinates each detail to the entirety and completes the knowledge.
>
> . . . Taken as a whole, these functions makes up a truly unified category, despite the differences in their aspects. They are all caused by environmental actions modified in the forms and are refracted in a series of effects. Science has not yet systematized their order and even lacks the proper term to name the general force that produces them.
>
> Specific powers have of course been imagined to explain certain functions, such as life or vital forces and the soul or physical forces; but these imagined agents vested with partial functions arouse serious objections as did the discredited agents of early Physics. It would be in accordance with the methods of science to attribute all the functions to a single force of the same order as gravity, physical action and affinity. We shall give it the broadest name of 'the force of activity.' (Bourdeau 2000, 21–23)

When Bourdeau posits that diverse functions in nature are comprised by "a truly unified category, despite the differences in their aspects," and that "they are all caused by environmental actions modified in the forms and are refracted in a series of effects," one finds these notions echoed loudly in the environmental decoherence interpretations of quantum mechanics being developed by many of the best-regarded quantum theorists of our time, including Nobel laureate Murray Gell-Mann, Roland Omnès, Robert Griffiths, and others. These physicists, despite their individual differences of approach, have each posited conceptions of quantum physics that aim at the very same unification described by Bourdeau, including the function of the environment in that unification. These thinkers each attempt to unify quantum and classical descriptions of nature, for example, and stress the function of the environment in quantum measurement interactions. In addition, they all begin with von Neumann's approach toward "quantum measurement," described earlier as "quantum praxis," and similarly repudiate the classical notions of "subject" and "object" by way of this concept.

Just as important to both the praxiology of Bourdeau and these modern interpretations of quantum physics, however, is the physical distinction between the order of causal relation and the order of logical implication. Bourdeau writes:

> The work of function is quite specific and must not be mistaken, as is sometimes the case, for that of modality or composition. A function is characterized by the order of its developments owing to the unity of direction [i.e., an asymmetrical logical order] which the structure imposes upon concurrent forces. (Bourdeau 2000, 23)

And indeed, temporal and logical asymmetry must be a part of any coherent ontological interpretation of quantum mechanics. One finds, for example, a close connection between Bourdeau's words (quoted earlier) and Heisenberg's insistence that "every act of observation is by its very nature an irreversible process; it is only through such irreversible processes that the formalism of quantum theory can be consistently connected with actual events in space and time" (Heisenberg 1958, 52). And similarly, the research programs of Gell-Mann and others make explicit appeals to the logical order as somehow "physically efficacious" in or "governing of" processes such as decoherence and non-local, EPR-type quantum mechanical measurement interactions (cf. Omnès 1994 and Griffiths 2002 as examples).

The mathematical foundations of the relational realist philosophy, and its relation of the causal and logical orders by mutual implication in the unifying context of a unit of quantum praxis, are illustrated most concretely in the simplest model: Peano's. This is based on a successor operation ι converting any integer "moment" to the next, n to $\iota\, n = n + 1$. Peano later generalized ι to the unit-set-generating operation ι in his set theory, converting any set s of any cardinality into the unit set $\iota\, s = \{s\}$; we call this *unition*. The Peano causal order ι presupposes a logical order represented by the inclusion relation $s' \subset s$ holding between any set $s \subset \mathbb{N}$ regarded as defining a predicate or class of integers, and any subset $s'$of s (Finkelstein 2002).

The quantum theory of Bohr and Heisenberg was the first physical theory to transcend the mechanical notion of absolute truth implicit in mathematics; Heisenberg called it "non-objective." Like an integer, physical systems seem to have maximal descriptions, and unlike an integer, these are incomplete; every predicate has complementary ones. Bohr and Von Neumann, respectively, renounced and revised classical logic in formulating quantum theory, and this can be seen as renouncing the classical conception of *ontology,* and its bipolar distinction from epistemology, *for praxiology*—a theory of relational action. Because all actual observations make changes in the system beyond our control, it is therefore *not* assumed that a system can be qualified in the context of an absolute ontology, except as a singular limit $\hbar \to 0$, but only in the context of an absolute praxiology—a network of quantum processes represented by an operator algebra associated with the system.

Most quantum theory to date has retained the classical theory of the causal order and an absolute space–time, projecting these pre-quantum concepts into the quantum microcosm in what has long been recognized as "unphysical." Such mixed quantum/classical field theories are structurally unstable and singular, as well as false to actual practice. They challenge us to reconstruct the physical theory of the causal order based on explicit linkages with the logical order.

Just as classical unition ι (taken with union) generates classical set theory, a quantum unition operator ι generates a quantum set theory rich enough for field theory. Like classical set theory, this quantum set theory comes with no manual for building a physical theory with its tools. This is provided by a correspondence principle generalizing Bohr's, which is implicit in a suggestion by Irving Segal: Present-day singular physical theories are singular limits of a regular physical theory. Slight errors in the commutation relations have converted simple Lie algebras into nearby non-simple ones. According to my colleague David Finkelstein in a recent communication:

> This suggests that a suitable Lie algebraic (i.e. the algebra characterizing a physical theory's transformations, as idealized in an infinitesimal limit) simplification can restore the hypothetical regular theory (i.e., a theory devoid of singularities which are denotive of a theory's failure to give definite information.) This is an extension of canonical quantization; one may call it simplification quantization. One way to implement it is to move physical theories from their singular foundations in classical set theory onto the regular foundations of quantum set theory, which provides the necessary variety of simple Lie algebras. 'Simplification quantization' regularizes singularities that have eluded canonical quantization, while maintaining agreement with experiment. Simplification quantizations of gauge theory in general and of the gravitational theory of the causal order in particular are currently being investigated.
>
> This hypothesis provides an origin for the important Lie algebras of quantum physics, including the Lorentz, Heisenberg, Poincaré, and unitary ones. The basic Lie algebras define the statistics of quantum aggregates. These then generate kinematical algebras—i.e., algebras characterizing all possible dynamical outcomes of a quantum system, as underwritten by the theory. Finally, the operators in kinematical algebras that are symmetries of organized modes like condensates make up the symmetry groups and Lie algebras. In this approach, there are no truly fundamental symmetries in nature. Empirical symmetries tell us about the symmetry of some organized substratum and are contingent upon that organization. Space-time curvature and classical gravity can now be regarded as residual effects of the quantum non-commutativity of a simple space-time-energy-momentum Lie algebra near the singular limit of classical space-time.

These and other exemplifications of logical causality via a relational realist interpretation of fundamental physics might ultimately reveal deeper levels of systematic distinctiveness among recent interpretations of quantum mechanics; and at the same time, they might point to a broad unification of the sort proposed by Bourdeau—a unification that is at once speculatively metaphysical and demonstrably physical. Given the current state of quantum theory as an arena of competing interpretations, the philosophical basis of any metaphysical preference—be it a speculative dipolar quantum praxiological scheme such as the one proposed by the philosophy of relational realism, an absolutist classical mechanical-material scheme, a positivist scheme, or any other—would beg as robust an exploration as the physical basis, at least insofar as philosophy can serve as a valued conversation partner in such explorations. That is, if a physical theory can summarily trump a metaphysical theory via the desideratum of empirical adequacy, then the desideratum of logical coherence and consistency should similarly empower metaphysics, such that a speculative metaphysical argument could entail a significant critique of some particular interpretation of quantum mechanics.

If, for example, one presupposes the neo-classical dualism of actuality and potentiality as foundational to the interpretation of quantum physics, one might further wonder: Can the advantages, suggested by Heisenberg, of understanding actuality and potentiality (or the causal and logical orders) as connected yet mutually exclusive features of reality, be preserved and indeed improved within a more coherent monistic/quantum praxiological scheme, such as the one given in the philosophy of relational realism outlined herein? For by such a scheme, actuality and potentia, causal relation and logical implication, are not conceived of as mutually exclusive, bipolar features of reality, but rather mutually implicative, dipolar features of fundamental, unified, quantum praxis events. The crucial question then becomes: Can such quantum praxis events be scientifically *and* philosophically well-described as the Aristotelian *infimae species*—the elusive "final real thing"?

Again, this is the interpretation of quantum physics suggested by Alfred North Whitehead, who developed his event-ontological metaphysics during the same years that Heisenberg, Bohr, and their colleagues were developing the quantum formalism. Recent work has proposed a close compatibility between Whitehead's metaphysical scheme and modern interpretations of quantum mechanics (cf. for example, Hattich 2004 and Epperson 2004).

It might be argued that ontological dualisms such as the one proposed by Heisenberg (and the associated epistemic dualism proposed by Bohr) provide for "cleaner" accommodations of the physics—such that, for example, causal relation in physics enjoys its status as a "concrete," ontological, "physical" reality, and logical implication is restricted to an "abstract" epistemic "conceptual" reality. But it can also be said that a coherent dipolar monistic metaphysical scheme such as that given in the philosophy of relational realism and its quantum praxiological model, and the closely associated scheme proposed by Whitehead, each with its close correlation of ontological and logical first principles, is "cleaner" than any such dualistic scheme (cf. Eastman 2004). The relational realist, dipolar-monistic quantum praxiological scheme may appear more *complex* insofar as it lacks any sharp speciation of reality into actuality and potentiality, concrete and abstract, physical and conceptual, causal and logical, as fundamentally mutually exclusive features of reality. But the relational realist scheme provides a *coherent* complexity, such that actuality and potentiality are seen as mutually implicative features of reality, as are the physical and conceptual features, and the causal and the logical features.

In this regard, it can be argued that a dipolar, monistic, quantum praxiological scheme such as that given by the philosophy of relational realism is "cleaner" than any simply dualistic scheme that might be *mostly* coherent but nevertheless requires at least a few fundamental features that are mutually exclusive rather than mutually implicative. Our goal, as was Whitehead's, is a physical and speculative metaphysical scheme entirely free of such selective dispensations from coherence—especially those that would amount to foundational, ontological inconsistencies. Information-based attempts to interpret quantum theory, for example, can be viewed as reflective of Whitehead's dipolar event ontology, where "physical" and "conceptual" features of actuality are mutually implicative: "information," after all, is instantiated both physically and conceptually. Its formal structure has been precisely characterized by Shannon and von Neumann in terms of physical notions like entropy; and yet its content is nevertheless representational, that is, *irreducibly conceptual* insofar as fundamentally exhibiting "aboutness"—which is to say, information is always information *about*.

If, indeed, a coherent praxiological, relational realist interpretation of quantum physics finds its way to fruition and is seen as exemplifying a Whiteheadian type (or any other type) of metaphysical scheme, the desideratum of empirical adequacy will be of paramount importance. The metaphysics must accommodate the empirically validated features of the physical formalism. Interpretations of quantum physics such as those offered by Gell-Mann, Griffiths, and Omnès, for example, derive the logical order of classical causality, in part, from the decoherence effect, whereby potential facts constitutive of a quantum mechanical system are logically ordered into potential, mutually consistent histories. Decoherence is thus given by these interpretations as a derivation of classical logical causality from the quantum mechanical correlation of the causal and logical orders.

But if fitness is to be tested and evaluated among competing physical-metaphysical interpretations of quantum mechanics—that is, those that dualistically treat *actuality & the causal order* and *potentiality & the logical order* as separate or separable features of reality, versus the relational realist interpretation, which treats actuality and potentiality as dipolar, mutually implicative features of every quantum praxis event—it is equally crucial that the conception of experiment be sufficiently free of serious constraints imposed by any particular ontological commitment. This is especially important with respect to certain of these commitments that enjoy the status of "convention." Thus an emphasis on experimental testing, such as those discussed earlier, combined with reduced model-dependence, and a turn away from the typical conditioning influence of traditionally inherited ontological presuppositions, will be an important prescription for the development of metaphysically coherent interpretations of physical theories such as quantum physics. The EPR experiment, for example, was conceived by its authors via the conventional, inherited classical mechanistic-materialistic ontology. But more recent EPR-like tests of quantum nonlocality, rather than being conceived as constricted to this ontology, were conceived to test the limitations of this ontology.

Indeed, a physically substantiated speculative metaphysical argument such as that given in the philosophy of relational realism and its praxiological approach to quantum mechanics, briefly outlined herein, might thus find its way into the sciences as a useful new metric for theory evaluation. So long as the speculative metaphysical scheme includes empirical adequacy and logical coherence as key desiderata, it is difficult to argue against the possibility of such a metric becoming a non-trivial feature of the scientific enterprise and its central role in the continued evolution of the modern realist worldview; for both science and philosophy presuppose the same logical first principles, without which neither would be possible.

REFERENCES

Alper, M. 2006. *The "God" part of the brain: A scientific interpretation of human spirituality and God*. Naperville, IL: Sourcebooks.

Bohm, D. 1952. A suggested interpretation of the quantum theory in terms of 'hidden' variables. *Physical Review* 85: 166–193.

———. 1986. Time, the implicate order, and pre-space. In *Physics and the ultimate significance of time*, ed. D. R. Griffin, 177–208. New York: State University of New York Press.

Bohm, D., and B. J. Hiley. 1993. *The undivided universe: An ontological interpretation of quantum theory.* London: Routledge.

Bohr, N. 1958. *Atomic physics and human knowledge*. New York: Wiley.

Bourdeau, L. 1882. *Théorie des sciences: Plan de science integrale*, v2. Paris: Librairie Germer Baillière.

———. 2000. Praxiology as the science of functions. In *The roots of praxiology: French action theory from Bourdeau and Espinas to present days*, ed. V. Alexandre and W. W. Gasparski, 21–23. New Brunsmick, NJ: Transaction.

Eastman, T. E. 2004. Dualities without dualism. In *Physics and Whitehead: Quantum, process, and experience*, ed. T. E. Eastman and H. Keeton, 14–30. New York: SUNY Press.

Epperson, M. 2004. *Quantum mechanics and the philosophy of Alfred North Whitehead*. New York: Fordham University Press.

Espinas, A. 1882. *Théorie des Sciences: Plan de Science Integrale*. Paris: Librairie Germer Baillière.

Everett, H. 1957. 'Relative state' formulation of quantum mechanics. *Review of Modern Physics* 29: 454–462.

Finkelstein, D. 2002. *Quantum relativity: A synthesis of the ideas of Einstein and Heisenberg*. Berlin: Springer.

Gell-Mann, M., and J. Hartle. 1997. Strong decoherence. In *Quantum classical correspondence: The 4th Drexel Symposium on Quantum Nonintegrability*, ed. D. H. Feng and B. L. Hu, 3–35. Cambridge, MA: Intemation Press.

Gödel, K. 1931. Über formal unentscheidbare Sätze der Principia Mathematica und verwandter Systeme, I. *Monatshefte für Mathematik und Physik* 38: 173–198.

Griffiths, R. 1984. Consistent histories and the interpretation of quantum mechanics. *Journal of Statistical Physics* 36: 219–272.

———. 2002. *Consistent quantum theory*. Cambridge: Cambridge University Press.

Hartle, J., and S. Hawking. 1983. The wave function of the universe. *Physical Review D* 28: 2960–2975.

Hattich, F. 2004. *Quantum processes: A Whiteheadian interpretation of quantum field theory*. Münster: Agenda Verlag.

Heisenberg, W. 1958. *Physics and philosophy*. New York: Harper Torchbooks.

Omnès, R. 1994. *The interpretation of quantum mechanics.* Princeton, NJ: Princeton University Press.

Weber, R. 1986. *Dialogues with scientists and sages: The search for unity*. London: Routledge.

Whitehead, A. N. 1978. *Process and reality: An essay in cosmology* (Corrected Edition). New York: Free Press.