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THE COPENHAGEN INTERPRETATION OF QUANTUM PHYSICS:
AN ASSESSMENT OF ITS FITNESS FOR USE IN CHRISTIAN
THEOLOGY AND APOLOGETICS

A Dissertation
Presented to
the faculty of
The Southern Baptist Theological Seminary

In Partial Fulfillment
of the Requirements for the Degree
Doctor of Philosophy

by
Jeremy Royal Howard
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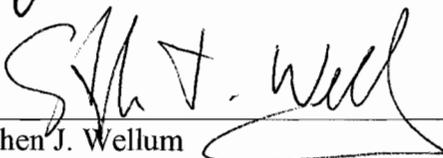
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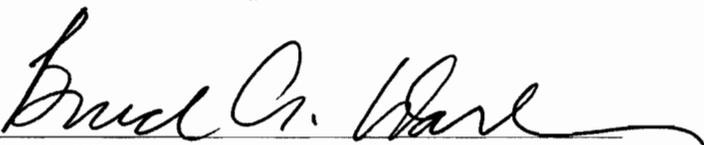
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THEOLOGY AND APOLOGETICS

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To Simone,
a gift from heaven, by way of Brazil

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PREFACE

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Jeremy Royal Howard

Louisville, Kentucky

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CHAPTER 1

INTRODUCTION

I argue in this dissertation that the Copenhagen interpretation (CI)¹ of quantum physics, an interpretation that posits a basic irrationality in the quantum realm, is not suitable for use in Christian theological formulation or apologetic engagement. Quantum mechanics is the branch of physics that studies the nature and behavior of atomic and subatomic entities. From the time of Newton's ascendancy to the dawn of the twentieth century, it was assumed that the steady march of scientific advancement would someday bring Newtonian descriptions to bear on nature's smallest components. On this assumption, tracing the activities of a quantum particle such as an electron should be as simple as obtaining values for variables such as position, momentum, and trajectory, and then projecting outcomes based on methods common to Newton's mechanics. Underlying this methodology are presuppositions that the world is by nature rational in structure and operation and that the scientific investigator is a mere observer rather than a participant in the experimental results he obtains via his tests.

Confidence in classical mechanics so pervaded Western society from the Enlightenment forward that philosophers and natural scientists came to believe that, in principle at least, a human investigator could foresee the future if he could but know all present mechanical variables. This is well illustrated by Pierre Laplace's famous claim that an omniscient intelligence could know the future exhaustively if it could grasp per-

¹Throughout this dissertation, I shall use the following terms interchangeably: Copenhagen interpretation, orthodox position, CI (for Copenhagen interpretation), or simply "Copenhagen," which designates the interpretation unless context indicates that the Danish city itself is in view.

fectly in an instant all the forces, components and relations that compose the natural realm.² Known as Laplacian determinism, this confidence in the far-reaching descriptive power of Newtonian science is a core component of common representations of the so-called Newtonian worldview. James Cushing notes that while this construal may fit with historic optimism regarding the explanatory power of classical mechanics, it actually misrepresents the true capacities of the system. Everyday mechanical systems, even simple ones, can exhibit chaotic behavior.³ Thus, Laplacian determinism may be an ideal that is actually inapplicable to any classical system. However, it is important to note that the inability of Newtonian mechanics exhaustively to eliminate chaotic elements is more a result of the investigator's limited knowledge of relevant factors than some genuine irregularity in the natural order.⁴ This is an important distinction from the tendency among quantum physicists of the Copenhagen persuasion to attribute quantum chaos not to investigative incapacities, but to the very ontology of the quantum entities. In summary, though Laplacian determinism based on Newtonian mechanics is impractical due to the finitude of human investigators, it nevertheless remains the case that, *in principle*, the Newtonian outlook sets up an expectation that the future states of a mechanical system (including the entire universe) can be predicted by accounting for all variables in the present state. Order begets order in a mechanistic universe.

²Though Laplace himself does not so name it, the vast intelligence to which he refers is commonly referred to as "Laplace's demon." The original reference is as follows: "We ought then to regard the present state of the universe as the effect of its anterior state and as the cause of the one that is to follow. Given for one instant an intelligence which could comprehend all the forces by which nature is animated and the respective situation of all the beings who compose it—an intelligence sufficiently vast to submit these data to analysis—it would embrace in the same formula the movements of the greatest bodies of the universe and those of the lightest atom; for it, nothing would be uncertain and the future, as the past, would be present to its eyes. The human mind offers, in the perfection which it has been able to give to astronomy, a feeble idea of this intelligence. Its discoveries in mechanics and geometry, added to that of universal gravity, have enabled it to comprehend in the same analytical expression the past and the future states of the world." From Pierre Simone Laplace, *A Philosophical Essay on Probabilities*, trans. Frederick Truscott and Frederick Emory (New York: Dover Publications, 1951), 4.

³James T. Cushing, *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony* (Chicago: University of Chicago Press, 1994), 209-12.

⁴As Cushing explains it, "The generic source of this classical dynamical chaos is the *exponential* separation (in time) of system trajectories (in phase space) so that there is extreme sensitivity to initial conditions, leading to loss of effective predictive ability for the long-term behavior of the system," where "phase space" designates a mathematical space charting coordinates for position and momentum. *Ibid.*, 213. See also 271 n. 46.

Given the impressive success of the Newtonian program, scientists operating up to the dawn of the twentieth-century naturally expected that even the microphysical world, thought to be a diminution of the macroscopic order, would yield classical results. The realization that this is not so came as a sharp shock to scientists and laypersons alike. Physicists and interested onlookers were jolted out of a centuries-long habit-of-mind, and the result has been a sort of “outrage” that has not abated in a century of years.⁵ As the following survey will demonstrate, the quantum realm does indeed seem otherworldly, and it is no wonder that physicists and philosophers alike have disputed the possible implications.

The word “quantum” refers to the smallest units into which a given thing can be divided. In quantum physics specifically, the term refers to the tiny packets of energy by which atomic exchanges occur. Physicists were first pointed in this direction by the experiments of Max Plank. Plank concluded from his study of blackbody radiation that atoms do not trade energy in regular, even portions as do macroscopic systems such as the burners in our ovens; rather, atoms absorb and retain energy fitfully. For example, an atom may retain its entire quantity of energy for an indeterminate amount of time and then discharge in an unpredictable exothermic flurry a packet (quanta) of that energy. The irregularity of such atomic operations evoked a host of new questions from physicists. Does the irregularity indicate that Newtonian physics is merely a limit-case theory? Do quantum entities obey some set of unknown non-Newtonian laws, or are they genuinely lawless and indeterminate? Physicists and philosophers of science are divided over whether or not these important questions have been answered definitively.

As if Plank’s discovery was not unsettling enough, physicists soon compiled

⁵My use of “outrage” stems from Danah Zohar, who champions common quantum anomalies in an effort to formulate a quantum worldview. I will make significant reference to her work in later chapters. On quantum outrage, see Danah Zohar and Ian Marshall, *The Quantum Society: Mind, Physics, and a New Social Vision* (New York: Quill, 1994), 38.

additional anomalies from both empirical and *gedanken*-experiments.⁶ In the paragraphs to follow, I will summarize a handful of quantum science's more puzzling features. I will endeavor to present these in a manner that is independent of any specific interpretation of quantum phenomena and explain them only as they appear experimentally apart from relevant interpretive questions.⁷

The Two-Slit Experiment and the Measurement Problem

The double-slit experiment is perhaps the most vivid illustration of the mysterious nature of quantum phenomena. The classic form of the experiment is conducted in demonstration of the wavelike nature of light. Imagine a stream of photons is emitted from a light that is aimed at a solid partition (such as a wall) that has a single small slit, *A*, carved into its middle. Naturally, most of the photons will be stopped by the partition, but those which shine through *A* will carry on past the partition to illuminate whatever lies on the other side. In our case, what lies on the other side of the first partition is a second partition, only this one has two slits (*B* and *C*) instead of one, and they are positioned vertically in such a way that one of them is located higher than the position of *A* and the other lower. Finally, back of the second partition is a blank wall or screen that is set to receive whatever light has made its way past both partitions. If light were merely particulate, like bullets shot from a rifle, we would expect either the second partition to block all photons from passing on to the reception screen since neither *B* nor *C* are aligned with *A*, or else the reception screen to register only two meager "piles" of photons which had somehow ricocheted off the lip of *A* and made their way through *B* or *C* and landed in a fairly narrow zone aligned behind *B* and *C* of the second partition. In fact, the true result is quite

⁶So-called *gedanken*-experiments (thought-experiments) are often the only initial avenue available to scientists for the testing of advanced theories. This is especially so in quantum physics, for the microphysical scale is vanishingly small, a fact that demands a level of precision often unmatched by current laboratory equipment or conceptual schemata. Hence, thought-experiments are valuable tools for pushing past boundaries even as their returns can never rise to the level of indisputable scientific proof.

⁷The most significant quantum anomalies stem from famous thought-experiments which aimed to reduce the Copenhagen interpretation to absurdity. These experiments (the EPR-experiment and Schrödinger's Cat) are treated in chapter 2.

different from this expectation. The reception screen actually registers an interference pattern in which light and dark zones alternate vertically over a wide section of the screen. Amazingly, the zones that are most brightly lit do not fall directly behind B and C of the second partition. To the contrary, the single brightest zone on the reception screen falls in the area that is directly correspondent to the solid zone located between B and C of the second partition. In other words, while we might expect that the solid state located between B and C of the second partition would cast a “shadow” on the corresponding area of the reception screen, such that no photons are registered there, the fact is this area ends up recording the most photons. *This* experiment seems to indicate that photons are waves rather than particles.

Importantly, a similar experiment can be conducted using a beam of electrons rather than photons. Since the same interference pattern results from firing electrons through slits A , B , C of the two partitions, initial indications are that electrons are wave-like versus particulate. However, note this important point. When the experimenter elects to fire electrons (or photons for that matter) singly rather than as a beam, a most unexpected pattern develops. When a single electron is fired from the source, such that it passes through A , the reception screen receives the electron as a point-like notation. That an electron could arrive in such a manner indicates that it has a specified location at the reception screen, a behavior no wave can manifest. However, after many electron firings, a wave pattern nevertheless results on the reception screen just as was the case when a whole stream of electrons was fired at once. In this case, when electrons are fired singly, the wavelike result that builds up on the reception screen is the effect of an aggregation of the many single electron registrations. Thus, it seems that each individual electron travels through the partitions in a wavelike capacity—which explains the eventual build-up of the wave-pattern distribution on the registering screen—but arrives at the screen as a particle since it makes a point-like notation when it arrives.

Furthermore, that the consecutive firing of single quantum particles (be they electrons or photons) produces the same classic wave interference pattern displayed when whole groups are fired at once indicates that single quantum entities apparently do not behave as if they are traveling autonomously. It seems that each individual particle somehow plays a part in the greater drama, conducting itself according to a “dialogue” with the actions of particles making the transit before and after it. This, at least, is a fair telling of the initial impression one receives upon understanding the experimental results, for it is remarkably peculiar that a succession of singly fired *particles* should work in concert to build a *wave* interference pattern on the receptor screen. Is it not the case that interference is possible only when multiple entities are commuting simultaneously? Apparently not in the quantum world.

The appearance of “dialogue” is heightened when one notes the fact that the experimenter can seemingly force quantum entities to manifest particle or wave characteristics depending on exactly what sort of experiment he sets up, as when he chooses to set up a device that detects which of the slits (*A, B, C*) the particle passes through on its way to the detection screen, or as when he fires the particles singly rather than as a jam-packed stream. In this case, it seems the particles are toggling back and forth between wave and particle manifestations as they dialogue with the lab equipment and the will of whatever observers happen to be present.

This chimerical behavior leads to an obvious problem for the experimenter. While physicists conducting experiments on classical systems—where Newtonian assumptions and formulations hold—know that their measurements have some effect on the objects under observation, they are safe to discount such effects as negligible. Measuring wind speed, for instance, slows the wind a bit, but by a factor too small to matter. In contradistinction to this, quantum experiments by their very nature will incline the observed objects to produce one or another contrary possibilities. Commonly referred to as the *quantum of action*, Louis de Broglie calls it the “spoil-sport” of the physicist’s specula-

tions.⁸ In the face of such a thing, one may wonder what hope the physicist has of describing reality apart from his choice of experimental set-up. Hunt for a particle, and a particle you will find. Seek a wave, and it is there in place of the particle. Search for the quantum reality that exists apart from your biasing of the situation, and you will find yourself shutting your machinery down on your way out the door.

In all, this is but one of the sources of uncertainty that we will discuss in this dissertation.⁹ Quantum entities always give us exactly the answers we are looking for, and in doing thus they answer us nothing.

Quantum Probabilities

The difficulty of nailing down appropriate descriptors for quantum entities highlights just how far the new physics diverges from classical mechanics. Newton favored modeling light as corpuscular. What would he say to evidence that it is apparently that and its contrary as well? Physicists have taken to the use of the term “wavefunction” to denote the quantum state. Sam Treiman explains what this designates.

What does the wave function signify? Everything. According to the principles of quantum mechanics the wave function incorporates all that can be known about the state of the system at any instant. But it does not in general tell where the particles are located or what their momenta are. What it gives us, and that's all we can know, are *probabilities* concerning the outcomes of various kinds of measurements that might be made on the system, measurements of position, momentum, energy, angular momentum, and so on.¹⁰

Thus, whereas Newtonian mechanics aimed at exacting description of both entity and event, quantum physics settles for probabilistic descriptors of both. What a quantum entity happens to be, and what it happens to do, are at best *statistically* described. The phenomenon of radioactivity illustrates this well. If an experimenter isolates a radioactive atom, she can be confident that it is set to decay at some future time. However, she

⁸Louis de Broglie, *Physics and Microphysics*, trans. Martin Davidson (New York: Pantheon Books, 1955), 110.

⁹Werner Heisenberg's famous Uncertainty Principle is discussed chapter 2.

¹⁰Sam Treiman, *The Odd Quantum* (Princeton: Princeton University Press, 1999), 25.

does well to go on with her daily activities, for the fact is the exact time of the impending decay event is unknown. She may predict it broadly as a function of probability, but never narrowly as a function of regular mechanistic process. Newton and his mechanics, it seems, are detained at the entrance to the quantum domain.

Non-Locality

A final curiosity will complete this introduction to quantum science. In classical physics, cause-and-effect is assumed to be an entirely local phenomenon. If billiard ball D suddenly darts across the billiard bed and lands inside a pocket, the sensible physicist will look for an immediate local cause for D 's sudden change of momentum. Has either the cue or the cue ball struck it? Or perhaps an object ball was sent careening into D ? In any case, anyone suggesting that the cue ball on the adjoining table, while keeping between the bumpers of its own proper table, had sent D racing toward the pocket would rightly be dismissed from the discussion.

Not so in quantum billiards. In fact, try as we might (and have, for seventy years and more) to dispel it, genuine non-locality seems to be a settled fact of quantum reality. As demonstrated in greater detail in the following chapter, quantum particles that share a common past may carry on affecting one another even in the event that they become too widely separated to allow for any form of contact action or physical communication. This is yet another indication that quantum science is opening the way to a world undreamed of by our forbearers.

The Current State of Quantum Physics

If quantum physics presents so many extraordinary anomalies, might we hope that it is due to be replaced by thoroughgoing Newtonian descriptions at a later date? This is generally regarded as unlikely. Following are some of the chief reasons.

Quantum Mechanical Fruitfulness and Mystery

Quantum physics is a rousing success despite the many controversies that swirl around its interpretation. In fact, it is said that quantum theory has more explanatory power than any other theory in the history of science.¹¹ Applications of quantum theory have led to the following list of impressive advancements: more adequate explanation of chemical bonding; advanced development of microelectronic devices such as silicon chips and lasers, leading to the modern communications explosion; medical technology advances, including magnetic resonance imaging; comprehension of superconductivity; postulation of comprehensive physical theories that seek to unify all physical causes and effects into a single theory for everything; and a host of other commercial and scientific applications.¹² When all the commercial products and services that are either made possible by or improved by quantum technology are added up, we find that a whopping thirty percent of America's gross national product involves quantum science.¹³

Given the fruitfulness of quantum theory, it would seem sensible to suppose that scientists and philosophers have a pretty good grasp of what quantum theory means. The opposite is true, in fact. Murray Gell-Mann says physicists know how to use quantum theory, but are in the dark about its meaning. He suggests we speak of a quantum *framework* rather than quantum theory, for this leaves open the possibility that an understandable theory might someday be fitted to the already useful framework within which quantum physicists work.¹⁴ This is an exceptionally important suggestion, and one that I

¹¹Wesley C. Salmon, *Four Decades of Scientific Explanation* (Minneapolis: University of Minnesota Press, 1989), 173.

¹²Christopher Norris, *Quantum Theory and the Flight from Realism: Philosophical Responses to Quantum Theory* (New York: Routledge, 2000), 25; Alain Aspect, "Introduction: John Bell and the Second Quantum Revolution," in *Speakable and Unsayable in Quantum Mechanics: Collected Papers on Quantum Philosophy* (Cambridge: Cambridge University Press, 2004), xvii; Steven Weinberg, *Dreams of a Final Theory* (New York: Pantheon Books, 1992), 65-66.

¹³Max Tegmark and John Archibald Wheeler, "100 Years of Quantum Mysteries," *Scientific American* 284 (February 2001): 69.

¹⁴Murray Gell-Mann, "Questions for the Future," in *The Nature of Matter: Wolfson College Lectures 1980*, ed. J. H. Mulvey (Oxford: Clarendon Press, 1981), 169-70.

will return to in the conclusion of this study.

Attempting to understand quantum theory is a fool's errand according to most physicists. Steven Weinberg says the attempt has derailed promising careers.¹⁵ Richard Feynman, one of the brightest minds ever to tackle quantum physics, warned students away from the error that knocked one of Weinberg's promising young student's completely out of physics.

I think I can safely say that nobody understands quantum mechanics. So do not take the lecture [on quantum theory] too seriously, feeling that you really have to understand in terms of some model what I am going to describe, but just relax and enjoy it. I am going to tell you what nature behaves like. If you will simply admit that maybe she does behave like this, you will find her a delightful, entrancing thing. Do not keep saying to yourself, if you can possibly avoid it, 'But how can it be like that?' because you will get 'down the drain', into a blind alley from which nobody has yet escaped. Nobody knows how it can be like that.¹⁶

Note that Feynman essentially bids his listeners to give up trying to conceptualize quantum physics. Live with the paradoxes, celebrate them even, but leave off the search for deeper, classically patterned understanding. As will be demonstrated in subsequent chapters, this so closely resembles the basic approach outlined by Bohr and his associates that it could pass as the charter statement of the CI.

Formalism and Interpretation in Physical Theory

How can quantum theory be the most fruitful theory in the history of science even as all the brightest minds admit that it is also the most mysterious? To answer this, one must distinguish two components of quantum theory. Every physical theory has both a formalism and an interpretation. The formalism is "a set of equations and a set of calculational rules for making predictions that can be compared with experiment," while the

¹⁵Weinberg, *Dreams*, 84. Elsewhere in the same work, Weinberg says theoretical physicists play one of two roles: sage or magician. That a leading scientist would describe his line of work as magic is a good indication of the sort of territory staked out by many leading quantum theorists. *Ibid.*, 67. John Polkinghorne likens quantum theory unto a powerful drug that must be handled with great care. See John Polkinghorne, *Quantum Theory: A Very Short Introduction* (Oxford: Oxford University Press, 2002), 92.

¹⁶Richard Feynman, *The Character of Physical Law* (Cambridge, MA: M.I.T. Press, 1965), 129.

interpretation of a physical theory postulates ontological explanations for the observed phenomena.¹⁷

In quantum theory, it is the *interpretation* that is shrouded in mystery. The mathematical formalism is mostly uncontroversial and is accepted by virtually all parties, no matter their interpretational leanings. Since the formalism is all one needs to build better lasers and otherwise advance the kingdom of science, most practicing physicists use the quantum formalism and entirely ignore the controversy over interpretation.¹⁸ Since a key difference between the Copenhagen interpretation and alternative views is the question of whether or not quantum indeterminacy is a reflection of nature itself or current human conceptual and investigative limitations, the tendency for physicists to practice quantum physics in disregard to its interpretation means physics has gotten on quite well without solving a vital ontological question: have we or have we not found genuine acausality in the physical world? Where one comes down on this question is not dictated by the quantum formalism or the empirical results obtained in the laboratory. Rather, the decision about acausality is decided on philosophical grounds, which are themselves a matter of personal taste.¹⁹ In this light, it is no surprise that most practicing physicists regard the interpretation of quantum theory as baggage that is best left on the curbside, for

¹⁷Cushing, *Quantum Mechanics*, 9. Dipankar Home says the “interpretation provides physical content to a theory in terms of some key concepts,” and names as an example “the concept of force as a cause for acceleration [which is] is crucial in understanding the basic equation of motion in Newtonian mechanics.” See Dipankar Home, *Conceptual Foundations of Quantum Physics: An Overview from Modern Perspectives* (New York: Plenum Press, 1997), 1.

¹⁸Alan Grometstein says physicists are exposed to issues in quantum interpretation in college, and then straightway push these aside when they leave the lecture halls for their careers in the laboratory. See Alan Grometstein, *The Roots of Things: Topics in Quantum Mechanics* (Boston: Kluwer Academic, 1999), 3. Brian Greene says physicists working in quantum mechanics simply follow the rules that were laid down by the founders of quantum theory even though they do not understand why the rules work or what they mean. Brian Greene, *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory* (New York: Vintage Books, 1999), 87. Bruce Wheaton notes that the Copenhagen interpretation represents the “public philosophical view of most physicists,” but that this is “unrelated to doing physics” and is therefore of “marginal professional concern to physicists.” See Bruce Wheaton, *The Tiger and the Shark: Empirical Roots of Wave-Particle Dualism* (Cambridge: Cambridge University Press, 1983), 307.

¹⁹Trevor J. Pinch, “What Does a Proof Do If It Does Not Prove? A Study of the Social Conditions and Metaphysical Divisions Leading to David Bohm and John von Neumann Failing to Communicate in Quantum Physics,” in *The Social Production of Scientific Knowledge*, ed. Everett Mendelsohn, Peter Weingart, and Richard Whitley (Boston: D. Reidel Publishing, 1977), 177.

scientific fact is far more relevant than philosophical opinion when one is in the hunt for a research grant. Nevertheless, when pressed to state an interpretational position, physicists will with impressive regularity cite the Copenhagen interpretation favorably. Reasons for this are discussed more thoroughly in chapter 5. For now, it is sufficient to say that contemporary physicists are only repeating the standard line that was fed to them throughout their undergraduate and graduate educations. That the interpretation seems irrelevant the moment physicists step into the laboratory leads to a sort of hardening of the common position by sheer indifference. Physicists learned the CI in school, noted that virtually everyone accepted it, accepted it themselves as a matter of expedience, came to question the value of debating fruitless interpretive issues, and hence never bothered to question what they and others had dutifully accepted by rite of long, venerable tradition. Copenhagen reigns among physicists partly because it just does not seem to matter. Add to this the fact that postmodernism champions certain of the elements vital to the CI, and everyday physicists must think things are getting on quite well without introducing needless dispute into the equation.

Introduction to the Copenhagen Interpretation

The Copenhagen interpretation takes its name from the Danish city where Niels Bohr established his Institute for Theoretical Physics. It was here that great physicists such as Bohr, Werner Heisenberg, Wolfgang Pauli, and a host of others collaborated throughout the second quarter of the twentieth century to provide an interpretation for quantum theory. A sample of core components of their interpretation includes the following: (1) the quantum theory, as developed by roughly 1930 and not since altered, is as complete a description of quantum phenomena as is possible, which entails, (2) that indeterminism is genuinely a characteristic of quantum events and not merely a reflection of current theoretical and investigative limitations, (3) that quantum acausality is one consequence of this indeterminacy, (4) that wave-particle duality is a complete description of a quantum system, such that wave and particle characteristics are said to be “complemen-

tary,” which on Bohr’s terms means quantum nature is properly described as paradoxical, and (5) that quantum systems remain indeterminate (undecided on such factors as wave or particle behavior, position, and momentum values) until they are observed either by a conscious being or measuring apparatus.²⁰ I will argue that several of these components are either actually or possibly contrary to elements in the Christian worldview, and that they betray philosophical bias and scientific insufficiency, all of which indicates that the CI should be rejected for use in formulations of Christian theology and apologetics.

Introduction to Thesis

I maintain that the Copenhagen interpretation of quantum physics is not suitable for use in Christian theological formulation or apologetic engagement. There are two main reasons this is so. First, the Copenhagen interpretation is not the assured deliverance of science. I will defend this claim by examining the philosophical and sociological background to the development of the Copenhagen interpretation with a view toward indicating that quantum theory can reasonably (and *preferably*) be interpreted along lines different from the orthodox program. I will do this by noting the pronounced philosophical bent of the key Copenhagen theorists and by surveying and adopting the Forman hypothesis, which states that the cultural milieu in post-war Germany fostered the radical overturning of all mechanistic conceptions in favor of irrationalist viewpoints. As these tastes have been sustained for nearly a century now, popularized and ensconced by the ascendancy of postmodernism, the CI has continued to dominate quantum theory in part because of its fitness with regnant worldview themes in science and philosophy. In this light, it seems likely that the orthodox view is vulnerable to the essential inevitability of a future worldview exchange. When irrationalist inclinations pass from the scene, the CI

²⁰This list is a compilation of components listed by several scholars. Among these are Christopher Norris, “Philosophy of Science as ‘History of the Present’: Quantum Theory, Anti-Realism, and Paradigm-Change,” *New Formations* 49 (2003): 25; David Lindley, *Where Does the Weirdness Go? Why Quantum Mechanics is Strange, but Not as Strange as You Think* (New York: BasicBooks, 1996), 107; Arkady Plotnitsky, *Complementarity: Anti-Epistemology after Bohr and Derrida* (Durham, NC: Duke University Press, 1994), 72; Grometstein, *Roots*, 410; and Cushing, *Quantum Mechanics*, 32.

may seem to have been little more than a faddish piece of philosophical world-making. Hence, to legitimize the CI by grafting it into theological and apologetic endeavors is to risk having the legitimacy of said endeavors carted away when scientific fashion shifts away from Copenhagen. I will also examine alternative interpretations of quantum theory, and highlight the fact that at least one of them is empirically equivalent to Copenhagen while retaining more classical assumptions about rationality and causality.²¹ This provides a scientific reason for opposing the CI.

The second main avenue for defending my thesis is an examination of the core elements of the Copenhagen interpretation. This will indicate that certain aspects of the CI are potentially or actually in conflict with important features of the Christian belief system. In particular, belief that the world is rationally structured and is reflective of God's own rationality is in danger of being swept away by Copenhagen indeterminacy and irrationality. A longstanding tradition in Christian theology indicates that the concepts of God's purposive, rational creation of the universe and his bestowal of his image on humanity has significant epistemological implications in the following way: the world is a creation of a rational God, reflects God's rationality in its structure and operations, and is in principle knowable by humans because the *imago dei* (by which we participate in the divine Logos, Jesus Christ) vouchsafes that our minds are operationally and conceptually capable of receiving true information about the world God made.²² Christian belief in the stability and rationality of the creation, as well as our God-designed rationality, are commonly cited as science-building presuppositions that helped Christianized nations pull off the scientific revolution while various Eastern cultures failed to do so.²³

²¹This is a reference to David Bohm's work. Bohm was aligned with the Copenhagen camp early in his career, but broke decisively from it after writing a textbook explaining quantum mechanics along orthodox lines. His alternative to Copenhagen is unpopular, and there are some noteworthy reasons for this. Nevertheless, the mere existence of his empirically equivalent hidden-variables approach shows that Copenhagen has not said the final word on quantum mechanics.

²²Ronald H. Nash, *The Word of God and the Mind of Man: The Crisis of Revealed Truth in Contemporary Theology* (Phillipsburg, NJ: P&R Publishing, 1982), 9, 59, 81, 131-32.

²³Stanley L. Jaki, *The Savior of Science* (Grand Rapids: Eerdmans, 2000), 65; Del Ratzsch, *Science and Its Limits: The Natural Sciences in Christian Perspective* (Downers Grove, IL: InterVarsity

Furthermore, the most common formulation of the CI's principle of complementarity opens the possibility of accepting contradictories as varying parts of a holistic system. This is commonly taken as a supporting evidence for worldviews that emphasize irrationality and deny realist conceptions of truth and world. As Christianity makes decisive claims about the existence of absolute truth, the impossibility of simultaneously instantiating contradictories, and the reality of the physical world, the principle of complementarity is in tension with the Christian worldview.²⁴ In conclusion, the adoption of key elements of the CI appears to be a betrayal of Christian commitments that are vital to sound theological and apologetic formulations.²⁵

Outline of Approach

Though this dissertation is about the scientific and philosophical characteristics of the Copenhagen interpretation of quantum physics, it is assuredly not an in-depth

Press, 2000), 136-38; Rodney Stark, *For the Glory of God: How Monotheism Led to Reformations, Science, Witch-Hunts, and the End of Slavery* (Princeton: Princeton University Press, 2003), 147; John Hedley Brooke, *Science and Religion: Some Historical Perspectives* (Cambridge: Cambridge University Press, 1991), 19. On cultures that lacked these key presuppositions, see Stanley Jaki, *The Road of Science and the Ways to God* (Chicago: Chicago University Press, 1978), 14-15, 34; Nancy R. Pearcey and Charles B. Thaxton, *The Soul of Science: Christian Faith and Natural Philosophy* (Wheaton, IL: Crossway Books, 1994), 22-9.

²⁴Nash argues that Christian Scripture indicates the existence of objective truth, and cites 1 Cor 15 and John 21:25 as examples. Ronald H. Nash, *Life's Ultimate Questions: An Introduction to Philosophy* (Grand Rapids: Zondervan, 1999), 248.

²⁵By "sound theological and apologetic formulations" I mean to indicate that the formulation and defense of the Christian worldview should be done in accordance with fundamental beliefs about God and world that have long been common to the Christian community, and which stem from careful exegesis of the Bible, the autographs of which are presupposed to have been the inerrant revelation of the Lord God, whose aim was to disclose in Scripture truth about God and world, and the extant manuscripts of which are taken to be preserved by the providence of God as reliable representations of the autographs. True (correspondent) knowledge about God and world is possible because God has made humans in his image, which fact includes but is not limited to our being made after his *rational* image. The laws of logic are reflective of God's own *rationes aeternae*. Language is a reliable tool for conveying truth because God designed language for that purpose and endowed humans with the capacity to sift through linguistic error and misrepresentation sufficiently to allow for the possibility of trustworthy communication. Furthermore, sound theological and apologetic methodology rests vitally on the conviction that prevailing scientific theories may inform theology and apologetics only insofar as such theories are exceptionally well established and do not finally controvert the teachings of the Bible, the relevant passages of which have been exegeted carefully so as to understand authorial intent. Hence, the practitioner of sound apologetics and theology should be prepared for the possibility that Christian belief may preclude one from adopting certain prevalent scientific theories when the claims and presuppositions of such theories present opposition to the intentional teachings of Scripture. In this light, for instance, if prevalent views in quantum physics indicate that the future is unknowable even to an omniscient God, Christian participants in the science-theology dialogue ought to firm up their allegiance to the historic and eminently biblical Christian teaching that God does indeed know all things, past, present, and future, and thus stand in opposition to prevalent scientific opinion.

treatment of the science of quantum mechanics. The mathematical apparatus (or formalism) of quantum theory was briefly discussed in non-mathematical terms only as a means of differentiating it from the real issue at hand: the interpretation. A few technical experiments are described in non-technical language. In some cases the reader may be satisfied to understand what the scientific consensus reports on a given experiment or quantum feature even if he cannot fully comprehend how relevant experiments are thought to support the consensus conclusions.

My sources fall primarily into two groups. First, there are sources published by physicists and philosophers of science who have engaged their peers in highly technical language. I will attempt to discuss this material in a manner that is at once highly accurate and yet palatable for the educated reader whose proficiency in physics does not rise above the capacities developed in introductory courses at college. Second, I will use sources that have shared something of my agenda, namely, the desire to write for educated readers whose knowledge of quantum physics is limited. In treating these latter sources, I will not “translate” them so much as simply pass them on to the reader.

Besides assessing the philosophical and scientific merits of the CI, I wish to evaluate it from a Christian worldview perspective. Specifically, I want to know whether or not the CI comports with core beliefs in Christianity. I have not found any comprehensive treatments of the CI from this perspective. Peter Hodgson has written an article that is to my knowledge the best treatment of the general subject, but his focus is not specifically the CI.²⁶ Dana Edgar Bible wrote a dissertation touching on some of the issues relevant to my topic, but his focus was likewise much broader than mine is.²⁷ Typically, Christian authors who have reservations about the CI offer a line or two mentioning rele-

²⁶Peter E. Hodgson, “God’s Action in the World: The Relevance of Quantum Mechanics,” *Zygon* 35 (2000): 505-16.

²⁷Bible’s work focuses on the “new physics,” which in his usage includes Einstein’s relativity theories as well as a variety of quantum mechanical interpretations. See Dana Edgar Bible, “Metaphysical Implications of the New Physics: An Assessment of Christian and Non-Christian Views” (Ph.D. diss., Southwestern Baptist Theological Seminary, 1986).

vant controversies.²⁸ Some theologians adopt quantum indeterminacy with little or no reservation as a means of defending various Christian concerns, but only rarely do they mention Copenhagen specifically.²⁹ In short, it seems that the role of the CI in quantum theory and worldview formulation remains a largely undeveloped topic in Christian scholarship.

Among secular scientists and philosophers, the CI has become something of a hot topic in the last fifteen years. As scientific realism has continued to enjoy a renaissance, critical interest in anti-realist, positivist, instrumentalist, and irrationalist elements in the CI has increased. While the clear majority of popular and semi-popular treatments of quantum mechanics are still written from within the Copenhagen fold, scholarly treatments are increasingly judicious in treating this orthodox view.

In chapter 2, I give a thorough account of the core interpretational components of the orthodox interpretation, for some of these set up potential conflict with Christian beliefs about God and the world he made. As there is no one founding document that delineates exactly what Copenhagen entails, an account of its core components is made possible only when the investigator culls together many witnesses, from both primary and secondary sources, that span eight decades. Several scholars have done this masterfully, and I will variously adopt or modify their conclusions. I also discuss how famed scientists such as Albert Einstein and Erwin Schrödinger attempted but failed to dissuade the physics and philosophy communities from adopting the CI by formulating landmark thought-experiments that aimed to expose absurdities entailed by said interpretation.

In chapter 3, I discuss how scholars and popularizers of science have applied Copenhagen to sociology, philosophy and science. Specifically, I make brief

²⁸Examples include R. Douglas Geivett, “The *Kalam* Cosmological Argument,” in *To Everyone an Answer: A Case for the Christian Worldview*, ed. Francis J. Beckwith, William Lane Craig, and J. P. Moreland (Downers Grove, IL: InterVarsity, 2004), 72; William Lane Craig and J. P. Moreland, *Philosophical Foundations for a Christian Worldview* (Downers Grove, IL: InterVarsity, 2003), 469.

²⁹Examples include the works of Nancey Murphy, Robert John Russell, and Thomas Tracy. These and other scholars are cited extensively in chapter 4.

notes on applications to such topics as feminism, race relations, finance, and business management. I will discuss in greater detail applications made in philosophy of science, epistemology, logic, and the sciences of consciousness and cosmology. I make a brief assessment of each of the above applications of the CI.

Chapter 4 is dedicated to the application of Copenhagen to metaphysics and theology. The CI is commonly named as a supporting evidence for Eastern and holistic worldviews. Several other applications are noted, but the main task of the chapter is to survey applications made in constructive Christian theology. In particular, I will examine the use of the CI in the free-will debate and scholarly discussions about divine action and omniscience. I make a brief assessment of these applications, with a view toward prefiguring my general conclusions to this study.

Chapter 5 is the heart of the dissertation. I show that the CI is unsuitable for adoption in Christian theological and apologetic endeavors for the following reasons: First, the CI, though it is the standard view in quantum physics, was actually forged by a handful of philosopher-physicists who consciously sought to ensconce indeterminism as an ontological rather than merely epistemological element of quantum theory. Second, there are several scientific and science-historical counter-indicators to the CI. It is possible, in fact, to formulate alternative interpretations of quantum theory that are empirically equivalent to the results for which Copenhagen accounts, and yet retain realism, rationality, and the principles of causality. Third, several entailments of the CI run counter to important elements in the Christian worldview.

In chapter 6, I intend to make a summary assessment of the Copenhagen interpretation and suggest avenues for continuing the science-theology dialogue in light of quantum science.

CHAPTER 2

THE COPENHAGEN INTERPRETATION OF QUANTUM PHYSICS

The man chiefly responsible for the Copenhagen interpretation is Niels Bohr. Setting aside all other ambitions, Bohr at a young age committed himself to the task of leaving a mark on both physics and philosophy. In a pair of definitive presentations in 1927, first at the Lake Como, Italy conference on physics in September, and then the following month at the Solvay Conference on quantum physics in Belgium, Bohr led fellow theoreticians such as Werner Heisenberg and Wolfgang Pauli in a charge that would see the CI of quantum physics established as essentially the only interpretive option for the foreseeable future.¹ As is discussed in chapter 5, Bohr had a remarkable talent for enlisting the passion and genius of the brightest physicists of his era. One after another they came to Bohr's laboratory in Copenhagen and offered him their services, the result of which was the forging of a new era in both physics and metaphysics. The ramifications of their work are comprehensive and as yet only partially developed.²

Bohr's interpretation of quantum mechanics is revolutionary and has produced many tangible effects in science, philosophy, and culture, and yet there is no official codifying document that sets down a definitive form of the CI.³ This leads Bas C. Van

¹Mara Beller says the CI is an "amalgamation" of the views of Bohr, Max Born, Werner Heisenberg, Wolfgang Pauli, and Paul Dirac. See Mara Beller, *Quantum Dialogue: The Making of a Revolution* (Chicago: University of Chicago Press, 1999), 143.

²For a sampling of the possible far-reaching ramifications of Bohr's work, see Arkady Plotnitsky, *Complementarity: Anti-Epistemology after Bohr and Derrida* (Durham, NC: Duke University Press, 1994), 83-84. Applications of the CI are treated extensively in chapters 3 and 4 of this dissertation.

³Peter R. Holland says it is remarkable that though the CI is the dominant interpretation of quantum physics, "there is no source one can turn to for an unambiguous rendering of Bohr's position

Fraassen to assert that the CI is really just “a roughly correlated set of attitudes expressed by members of the Copenhagen school.”⁴ Alan Grometstein says the CI is more a “spirit of inquiry” than anything else, and that it resembles the sort of mystic meditation manuals that Zen Buddhists or Quakers would produce.⁵ Peter Gibbins does not compare Bohr’s view to a meditation manual, but he does say the CI is a deep philosophy, the meaning of which is “extraordinarily unclear.”⁶

In light of such considerations, it is no surprise that at least one noteworthy commentator, Paul Feyerabend, concludes that it is nonsense to speak of a “Copenhagen school” of quantum physics.⁷ Feyerabend is substantially correct. Nevertheless, with Mara Beller I conclude that even though the various contributors to the CI did not agree on all points, such that there truly is no unified, finely formulated rendering of the orthodox view, it is genuinely possible to name as “central pillars” several doctrines that are foundational to a distinctly *Copenhagen* approach to quantum physics.⁸

Core Components of the Copenhagen Interpretation

The two most commonly cited features of the CI are indeterminism and complementarity.⁹ Following these, scholars often cite completeness, wave-function collapse,

about which there is general agreement.” See Peter R. Holland, *The Quantum Theory of Motion: An Account of the de Broglie-Bohm Causal Interpretation of Quantum Mechanics* (Cambridge: Cambridge University Press, 1993), 9.

⁴Bas Van Fraassen, *Quantum Mechanics: An Empiricist View* (Oxford: Clarendon Press, 1980), 280.

⁵Alan A. Grometstein, *The Roots of Things: Topics in Quantum Mechanics* (Boston: Kluwer Academic, 1999), 409.

⁶Peter Gibbins, *Particles and Paradoxes: The Limits of Quantum Logic* (Cambridge: Cambridge University Press, 1987), 48.

⁷Paul Feyerabend, *Farewell to Reason* (New York: Verso, 1987), 181.

⁸Beller, *Quantum Dialogue*, 187.

⁹For example, Christopher Norris, James Cushing, David Lindley, Mara Beller, and Abner Shimony all agree that ontological indeterminism is a core feature of the CI. See Christopher Norris, “Philosophy of Science as ‘History of the Present’: Quantum Theory, Anti-Realism, and Paradigm-Change,” *New Formations* 49 (2003): 25; James Cushing, *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony* (Chicago: University of Chicago Press, 1994), 32; David Lindley, *Where Does the Weirdness Go? Why Quantum Mechanics is Strange, but Not as Strange as You Think* (New York: Ba-

and holism as additional components. As we will see, each of these components interlocks with, grounds, or is entailed by the others, forming a phalanx of doctrines that stands in stark opposition to competing interpretations of quantum theory as well as historical concepts in science which in turn are linked to Christian worldview presuppositions.

Quantum Indeterminism

Commentators who favor the CI are keen to point out that quantum indeterminism means that the activities of quantum particles cannot be predicted because there is a fundamental acausality on the microphysical level. This indeterminism is not a function, they say, of current human ignorance; there is no hidden causal system embedded in quantum mechanics that awaits discovery.¹⁰ As we will see more clearly below, quantum non-locality is offered as one of the most important proofs for acausality. The logic is as follows: if two particles can affect one another instantaneously even though they are separated by a distance too great to be spanned spontaneously by any conceivable physical means, all real hope of identifying causal factors for quantum events seems lost. One could posit superluminal (faster-than-light) communication between quantum entities, but this cannot be proven feasible and in fact seems to be ruled out by Einstein's work with relativity theory.¹¹ Another argument for acausality stems from the surprising role the scientific observer (whether human or machine) seems to play in quantum measure-

sicBooks, 1996), 107; Beller, *Quantum Dialogue*, 187; Abner Shimony, "Search for a Worldview Which Can Accommodate Our Knowledge of Microphysics," in *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*, ed. James T. Cushing and Ernan McMullin (Notre Dame: University of Notre Dame Press, 1989), 27. On complementarity as a core feature of the CI, see, for example, Beller, *Quantum Dialogue*, 187; Cushing, *Quantum Mechanics*, 32; and Grometstein, *Roots*, 410.

¹⁰Plotnitsky, *Complementarity*, 72.

¹¹Menas Kafatos and Robert Nadeau, for example, rule out this possibility and conclude that non-locality indicates genuine acausality, See Menas Kafatos and Robert Nadeau, *The Conscious Universe: Part and Whole in Modern Physical Theory* (New York: Springer-Verlag, 1990), 113.

ments.¹² If “looking” at a quantum system changes it, surely all common notions of causality are inapplicable.

Contemporary adherents to the quantum indeterminacy model are in line with pronouncements Bohr himself made. Bohr thought the observation problem was the strongest indicator of quantum acausality. If the experimenter cannot describe the autonomous operations of a quantum system because her very measurements have helped produce the effect measured, causality has passed beyond our purview.¹³ The only conclusion to be made, says Bohr, is that quantum entities have “a free choice between various possible transitions” open to them.¹⁴ The scientist may find this situation maddening, but repudiation of causality is said to be the non-negotiable first step if progress is to be had in quantum science.¹⁵

Werner Heisenberg, whose contributions to the CI are eclipsed only by those of Bohr himself, was even more zealous to leave behind the classical concept of causality. He said that since “all experiments are subject to the laws of quantum mechanics,” we must conclude that quantum science “establishes definitively the fact that the law of causality is not valid.”¹⁶ David Cassidy notes that, for Heisenberg, acausality stems especially from his famed Uncertainty Principle, which states that it is impossible to know

¹²The role of the observer is discussed in more detail below. For now, keep in mind that a distinctive of the Copenhagen interpretation is the willingness to let appearances stand and not seek deeper meaning or causality. Thus, in cases such as the two-slit experiment the orthodox theorist is content to conclude that the quantum system does require an act of observation to collapse its potentialities into a specific actuality, whereas theorists outside the Copenhagen tradition will seek alternate explanations.

¹³Niels Bohr, “Causality and Complementarity,” *Philosophy of Science* 4 (1937): 293.

¹⁴Bohr, *Atomic Theory and the Description of Nature* (Cambridge: Cambridge University Press, 1934), 109.

¹⁵*Ibid.*, 108. Naturally, the supposition that observation forces the quantum system to manifest concrete values involves a sort of ‘causality’, but inasmuch as this brand of causality is so radically removed from traditional concepts of causality, quantum theorists of the orthodox party regularly speak of quantum acausality.

¹⁶Cited in Paul Forman, “Weimar Culture, Causality, and Quantum Theory, 1918-1927: Adaptation by German Physicists and Mathematicians to a Hostile Intellectual Environment,” in *Quantum Histories*, vol. 4 of *Science and Society: The History of Modern Physical Science in the Twentieth Century*, ed. Peter Galison, Michael Gordin, and David Kaiser (New York: Routledge, 2001), 216.

both the position and momentum of a quantum particle simultaneously.¹⁷

The initial values of the momentum and position cannot be measured simultaneously with absolute precision. As such, one can calculate only a range of possibilities for the position and momentum of the particle at any future time. Only one possibility will result from the actual motion of the particle. The causal connection between present and future is lost, and the laws and predictions of quantum mechanics become merely probabilistic, or statistical, in nature.¹⁸

Max Born, another significant member of the Copenhagen cohort, also taught that quantum science demands that the principle of causality be dropped and replaced by something different.¹⁹ Copenhagen apologists such as John von Neumann were quick to pitch their scientific weight behind the acausality claim with impressive mathematical formulas and dramatic flare, and thus it was not long before the view had carried the day among the persons whose opinions mattered most—the physicists.²⁰

Complementarity

Early steps toward a complementarity framework for quantum physics were indicated by difficulties involved in the attempt to study electrons.

¹⁷Actually, the exact meaning of the Uncertainty Principle is a matter of intense debate. Along realist lines, physicists may simply say the Principle indicates nothing more than our ignorance about the full range of values of the quantum system. Heisenberg originally called the Uncertainty Principle the Indeterminacy Principle, which reflects the orthodox party's belief that the quantum system is not only unknown to the experimenter, but that the system itself has no such values until measured. In Grometstein's words, the CI intends the Uncertainty Principle to mean that "such properties as position and momentum of an object are *latent qualities*, that is, until an electron is measured, it cannot be said to have position nor momentum." Grometstein, *Roots*, 424-25. That the "uncertainty" is grounded in a lack of ontological referent (no values exist unless measured) explains why Copenhagen theorists and apologists are so certain the *uncertainty* will never be overturned. For a particularly zealous defendant of the permanence of quantum uncertainty, see Norwood Russell Hanson, *Patterns of Discovery: An Inquiry into the Conceptual Foundations of Science* (Cambridge: Cambridge University Press, 1961), 149, and idem, "Copenhagen Interpretation of Quantum Theory," *American Journal of Physics* 27 (1959): 1-15.

¹⁸David C. Cassidy, "Heisenberg, Uncertainty and the Quantum Revolution," *Scientific American* 266 (May 1992): 111.

¹⁹Max Born, *The Restless Universe* (New York: Dover Publications, 1951), 155. As early as 1926, Born stated that he was inclined to give up causality in quantum physics. See Paul Forman, "Kausalität, Anschaulichkeit, and Individualität, or How Cultural Values Prescribed the Character and the Lessons Ascribed to Quantum Mechanics," in *Society and Knowledge: Contemporary Perspectives in the Sociology of Knowledge*, ed. Nico Stehr and Volker Meja (New Brunswick, NJ: Transaction Books, 1984), 336.

²⁰For John von Neumann's endorsement of acausality, see his *Mathematical Foundations of Quantum Mechanics*, trans. Robert T Beyer (Princeton: Princeton University Press, 1955), 328.

Historically, the position of an electron and the momentum of an electron were the first quantities to be recognized as having a complementary character, in the following sense: The equipment required to determine position, and the equipment required to determine momentum are *incompatible* with each other. They have such a character, no matter how ingeniously they are constructed, that they cannot *both* be used in studies on the same particle at the same time. Thus one can know the position at the cost of ignorance about momentum. Or one can know the momentum, with no opportunity to measure position. . . . Therefore one cannot dispense with either concept—either momentum or position—in the description of nature. However, one cannot use both concepts at the same time. In this sense the two are *complementary*.²¹

Here, the complementarity is between two non-contradictory values of the quantum particle. At base, all that is being said is that the scientist cannot *know* both values at once. It was Bohr who first used the term “complementarity” in application to quantum physics, and his use of the term differs from both the ordinary use and the use demonstrated above. Importantly, physicist and Copenhagen adversary John Bell concludes that “complementarity” for Bohr essentially means “contradictariness,” which of course is something of a reversal of its typical meaning.

It seems to me that Bohr used this word with the reverse of its usual meaning. Consider for example the elephant. From the front she is head, trunk, and two legs. From the back she is bottom, tail, and two legs. From the sides she is otherwise, and from the top and bottom different again. These various views are complementary in the usual sense of the word. They supplement one another, they are consistent with one another, and they are all entailed by the unifying concept ‘elephant’. It is my impression that to suppose Bohr used the word ‘complementary’ in this ordinary way would have been regarded by him as missing his point and trivializing his thought. He seems to insist rather that we must use in our analysis elements which *contradict* one another, which do not add up to, or derive from, a whole. By ‘complementarity’ he meant, it seems to me, the reverse: contradictariness. Bohr seemed to like aphorisms such as: ‘the opposite of a deep truth is also a deep truth’: ‘truth and clarity are complementary’. Perhaps he took a subtle satisfaction in the use of a familiar word with the reverse of its familiar meaning.²²

Bell has captured the essence of Bohr’s doctrine of complementarity. It is well that Bell does us this service, for while complementarity is Bohr’s most profound contribution to both physics and philosophy, he never presented it in systematic form. In fact,

²¹John Archibald Wheeler, *At Home in the Universe* (Woodbury, NY: American Institute of Physics, 1994), 231.

²²John Bell, “Six Possible Worlds of Quantum Mechanics,” in *Speakable and Unsayable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 189-90.

Henry Folse complains that where Bohr addresses complementarity, he generally leaves his terms undefined, with the result that “his arguments are frustratingly obscure.”²³ The further result, not surprisingly, is that no consensus exists on what exactly Bohr meant by the doctrine.²⁴ The student must piece together whatever scraps he finds sensible in Bohr and then consult the considerable body of secondary literature that attempts to elucidate the meaning of complementarity. Plotnitsky identifies the following as Bohr’s most lucent explanation of what he meant to convey.

The very nature of the quantum theory thus forces us to regard the space-time coordination and the claim of causality, the union of which characterizes the classical theories as complementary but exclusive features of the description, symbolizing the idealization of observation and definition respectively. . . . In the description of atomic phenomena, the quantum postulate presents us with the task of developing a ‘complementarity’ theory the consistency of which can be judged only by weighing the possibilities of definition and observation.²⁵

Many observers find this difficult to understand. Heisenberg explains Bohr’s viewpoint much more clearly in a discussion of the wave and particle characteristics of quantum entities.

Bohr advocated the use of both pictures, which he called ‘complementary’ to each other. The two pictures are of course mutually exclusive, because a certain thing cannot at the same time be a particle (i.e., substance confined to a very small volume) and a wave (i.e., a field spread out over a large space), but the two complement each other. By playing with both pictures, by going from the one picture to the other and back again, we finally get the right impression of the strange kind of reality behind our atomic experiments.²⁶

As Norris explains, Bohr took this as a justification for recasting rationality in new terms, terms that would allow one to suspend the choice between contradictory options such as wave and particle or even allow one to accept both options simultaneously

²³Henry J. Folse, *The Philosophy of Niels Bohr: The Framework of Complementarity* (Amsterdam: North-Holland Physics Publishing, 1985), 29.

²⁴Beller, *Quantum Dialogue*, 119.

²⁵Bohr, cited in Plotnitsky, *Complementarity*, 67.

²⁶Werner Heisenberg, *Physics and Philosophy: The Revolution in Modern Science*, vol. 19 of *World Perspectives*, ed Ruth Nanda Anshen (New York: Harper and Brothers, 1958), 49.

without committing logical fallacy.²⁷ Thus, while waves and particles are very plainly contradictory things, Bohr would have us accept both simultaneously as proper descriptors of quantum reality. This view is unacceptable on any realist construal of science, for it prohibits any intelligible conception of quantum nature.²⁸ According to Plotnitsky, a noteworthy advocate for the implications the CI has in the humanities, complementarity “deconstructs” classical physics and metaphysics because it “dislocates . . . causal dynamics.”²⁹ Only on some variety of a pragmatist or anti-realist philosophy can one embrace Bohr’s complementarity.

An indication that this reading of Bohr’s complementarity is accurate is the fact that he chose to place the symbol for Yin and Yang on his coat of arms when he was inducted into the Danish Order of the Elephant in 1947. Above the symbol, Bohr placed the phrase *Contraria sunt complementa*, or, “Opposites are Complements.” For Bohr, quantum physics had opened the way to Eastern conceptions of reality, including an acceptance of contradictories.

Further indication that the above interpreters have properly understood Bohr on complementarity is given by some of Bohr’s comments on the broader ramifications of complementarity. For instance, he said, “We must be prepared for a more comprehensive generalization of the complementary mode of description which will demand a still more radical renunciation of the usual claims of so-called visualization.”³⁰ As application of complementarity spreads, greater portions of reality will be shoved into a noumenal caste to which visualization and comprehension are inapplicable. Interestingly, even Communists were provoked by Bohr’s doctrine because they understood it to have com-

²⁷Christopher Norris, *Quantum Theory and the Flight from Realism: Philosophical Responses to Quantum Theory* (New York: Routledge, 2000), 247.

²⁸Dugald Murdoch, *Niels Bohr’s Philosophy of Physics* (Cambridge: Cambridge University Press, 1987), 232.

²⁹Plotnitsky, *In the Shadow of Hegel: Complementarity, History and the Unconscious* (Gainesville: University Press of Florida, 1993), 31.

³⁰Bohr, “Causality and Complementarity,” 294.

prehensive worldview ramifications. Complementarity was “outlawed” in the U.S.S.R. from 1947 to 1958 for fear of its potential applications outside physics.³¹ This reaction was no doubt partly inspired by the fact that several Nazi leaders expressed openly the belief that Copenhagen doctrines undermined Marxism and supported Party ideologies. Pascual Jordan, for instance, believed complementarity might support the Nazi race-biology program in the following way: acausality and purpose might be construed as complementary in biological processes, such that the purposeless determinism of Marxist materialism might be refuted.³² Jordan also produced propagandist pamphlets proclaiming that the Nationalist Socialist ideology, which had ushered in a “new epoch,” justified the revolution in physics. Hence, lines of justification supposedly ran in both directions between the new physics and the Third Reich. Jordan even went so far as to repeatedly cast Bohr in the image of *Führer*, an appellation which surely appalled the peaceful, mild-mannered Bohr.³³

In fairness to Bohr, he did sometimes take a stab at limiting the scope to which complementarity was applied in fields outside physics.³⁴ Inheritors of the Copenhagen tradition have taken many liberties, however, perhaps following Bohr’s example of applying complementarity to issues in fields such as biology (vitalism vs. mechanism issue), culture, and language. For instance, Leon Rosenfeld relays that Bohr believed of language that “whenever you come with a definite statement about anything you are be-

³¹See Andrew Cross, “The Crisis in Physics: Dialectical Materialism and Quantum Theory,” *Social Studies of Science* 21 (1991): 740; Loren Graham, “Complementarity and Marxism-Leninism,” in *Niels Bohr: A Centenary Volume*, ed. A. P. French and P. J. Kennedy (Cambridge, MA: Harvard University Press, 1985), 333.

³²John Heilbron, “The Earliest Missionaries of the Copenhagen Spirit,” in *Science in Reflection*, vol. 3 of *The Israel Colloquium: Studies in History, Philosophy, and Sociology of Science*, ed. Edna Ullmann-Margalit (Boston: Kluwer Academic, 1988), 215, 220.

³³M. Norton Wise, “Pascual Jordan: Quantum Mechanics, Psychology, National Socialism,” in *Science, Technology and National Socialism*, ed. Monika Renneberg and Mark Walker (Cambridge: Cambridge University Press, 1994), 238. On Jordan’s use of the new physics in Party propaganda, see Wise, “Pascual Jordan,” 224-25.

³⁴See, for instance, Bohr, “Causality and Complementarity,” 295.

traying complementarity.”³⁵ Wheeler and Plotnitsky, two of the most significant contemporary purveyors of Bohr’s thought, are both confident that complementarity properly has application in every field of thought.³⁶ Importantly, Folse claims that Bohr himself expected that “the quantum revolution would ultimately lead to a general complementaristic philosophy of empirical knowledge.”³⁷

In summary, the doctrine of complementarity obfuscates nature by (1) its insistence that conjugate variables such as position and momentum cannot both simultaneously have real values, and (2) that quantum entities are described by complementary properties, wave and particle, and that the tension between these two sorts of properties ought not to be resolved or explained away by a search for hidden variables or deeper comprehension. Importantly, as Shimon Malin explains, these stances seem to undermine a key presupposition of science: that nature can be understood, explained, and modeled in rational terms.

This premise has been the foundation of the scientific pursuit for over twenty-five centuries. . . . Bohr’s framework of complementarity, however, is an explicit rejection of Thales’ implicit claim [that nature can properly be explained and modeled rationally]. According to Bohr, *the entities that belong to the atomic and subatomic domains cannot be described by a single model.*³⁸

By this last line, Malin means to say that Bohr validates irrational approaches (approaches that incorporate conflicting models in a complementary fashion) to understanding nature.

Bohr and his fellow theorists dismiss the possibility that we simply have not yet accurately grasped the fundamental nature of microentities. No future advancements

³⁵Abraham Pais, *Niels Bohr’s Times, In Physics, Philosophy, and Polity* (Oxford: Clarendon Press, 1991), 446.

³⁶Wheeler, *At Home*, 19; Plotnitsky, *Complementarity*, 73-74.

³⁷Folse, *Philosophy of Niels Bohr*, 170.

³⁸Shimon Malin, *Nature Loves to Hide: Quantum Physics and Reality, a Western Perspective* (Oxford: Oxford University Press, 2001), 37. Thales of Miletus, Malin notes, is often considered the first scientist because he postulated a first principle in nature and sought to order nature in accordance with it.

will clear away current paradoxes, they say. Furthermore, from its very inception the complementarity doctrine has been seen as a component of worldview formulation. Bohr himself set the broad agenda despite the controls he haltingly espoused with several of his seemingly mislaid pronouncements. Once science accepts the genuine possibility that physical nature instantiates irrationality, it seems inevitable that application of such a radical view will spread to fields far removed from physics.

The Measurement Problem

The measurement problem, as defined by the CI, can be described as follows: acts of measurement do not provide the physicist with information about the preexistent status of a quantum system; rather, acts of measurement themselves force the fundamentally indeterminate quantum system to instantiate certain qualities.³⁹ The physicist has therefore not discovered anything about the real world if by “real world” we mean the world apart from him. Rather, he has joined the observed system with the observing systems (he and his equipment) to form an entangled reality. Nick Herbert provides a nice introduction to Bohr’s approach.

According to Bohr, quantum theory describes neither the quantum system nor the measuring device. Quantum theory applies to the *relationship* which exists between these two conceptually opaque kinds of being. . . . In the Copenhagen interpretation, all the mysterious transitions between the quantum and classical kinds of being occur inside the measuring device or more properly at the boundary between measuring device and quantum system. We see that the Copenhagen interpretation does not so much solve the measurement problem as conceal it. It sweeps this problem under the rug, into the one place in the world inaccessible to human scrutiny – the insides of measuring devices.⁴⁰

Hence, the so-called “collapse of the wave-function,” which refers to the act by which the indeterminate quantum system “collapses” to a definite value in response to being measured, is not properly construed as a description of quantum reality so much as

³⁹Beller explains that the measurement problem was inaugurated by Heisenberg’s Uncertainty Principle, for Heisenberg stresses the reduction or collapse of the indeterminate wave packet in the act of measurement. Beller, *Quantum Dialogue*, 67.

⁴⁰Nick Herbert, *Quantum Reality: Beyond the New Physics* (Garden City, NY: Anchor Press, 1985), 144.

it is a description of our *knowledge* of the system, and this knowledge is a contrivance since our measurements have created the determinate state.⁴¹ This creates a paradoxical situation in which the quantum system and the measuring instruments are at once conflated into a holistic system and yet kept separate in our descriptions of the experiment.⁴² At the end of the day, however, the CI maintains that the scientist is describing the holistic system and never the quantum system in and of itself, and that the scientist has “created” the values of this holistic entity.

Bohr himself warned against taking this “observer-created” aspect of quantum physics too far, for he recognized that some of the terms used to describe the situation do not trade equally between their common usage and that observed in the literature on quantum phenomena.⁴³ Specifically, Bohr seems intent on guarding against the idea that the observed quantum system does not exist prior to its being observed. If this is his point, as seems possible, it does not lessen the incredible nature of Copenhagen’s take on the measurement problem, for Bohr leaves uncontested the conclusion that the quantum

⁴¹Roger Penrose, “On Gravity’s Role in Quantum State Reduction,” in *Physics Meets Philosophy at the Planck Scale: Contemporary Theories in Quantum Gravity*, ed. Craig Callender and Nick Huggett (Cambridge: Cambridge University Press, 2001), 290. Gerald Holton explains that this situation differs from the measurement of classical systems in the following way: classical (macro) systems are considered to be closed systems because “the flow of energy into and out of the system during an observation (for example, of the reflection of light from moving balls) is negligible compared to the energy changes in the system during interaction of the parts of the system.” In contrast to this, quantum systems are “open” because the energy exchanges between them and the observation systems are highly significant, producing a syncretistic result. See Gerald Holton, “The Roots of Complementarity,” in *Quantum Histories*, vol. 4 of *Science and Society: The History of Modern Physical Science in the Twentieth Century*, ed. Peter Galison, Michael Gordin, and David Kaiser (New York: Routledge, 2001), 254. Charles Enz relays a helpful description given by Wolfgang Pauli: “In the new pattern of thought we do not assume any longer the *detached observer*, . . . but an observer who by his indeterminable effects (Einwirkungen) creates a new situation, theoretically described as a new state of the observed system. In this way every observation is a singling out of a particular factual result (eines realen Einzelereignisses), here and now, from the theoretical possibilities, thereby making obvious the discontinuous aspect of the physical phenomena.” Charles Enz, “The Science of Matter: Fascination and Limits,” in *On Quanta, Mind and Matter: Hans Primas in Context*, ed. H. Atmanspacher, A. Amann, and U. Müller-Herold (Boston: Kluwer, 1999), 226. Brian Greene explains that, on the standard view, the “collapse [of the wave-function] happens instantaneously across the whole universe,” such that the particle’s probable location has been reduced from literally anywhere in the universe to exactly one spot in the universe. Brian Greene, *The Fabric of the Cosmos: Space, Time, and the Texture of Reality* (New York: Knopf, 2004), 118.

⁴²Arkady Plotnitsky, “Complementarity, Idealization, and the Limits of Classical Concepts of Reality,” in *Mathematics, Science, and Postclassical Theory*, ed. Barbara Herrnstein Smith and Arkady Plotnitsky (Durham, NC: Duke University Press, 1997), 158.

⁴³Niels Bohr, *Essays 1932-1957 on Atomic Physics and Human Knowledge*, vol. 2 of *The Philosophical Writings of Niels Bohr* (Woodbridge, CT: Ox Bow Press, 1958), 63-64.

system itself is genuinely indeterminate until it is measured and thereby forced to manifest concrete values. However, there are some significant interpreters in Bohr's tradition who insist that Bohr not only meant to say that observation creates *values* for the quantum system, but that observation creates *the system itself*. Roger Penrose, for instance, says that on Bohr's view there is no objective quantum reality apart from measurement. "Nothing is actually 'out there', at the quantum level. Somehow, reality emerges only in relation to the results of 'measurements'."⁴⁴ Similarly, John Wheeler translates Bohr's point about measurement into this short sentence: "No elementary phenomenon is a phenomenon until it is a registered (observed) phenomenon."⁴⁵ Expanding this a bit, Wheeler says, "A phenomenon is not yet a phenomenon until it has been brought to a close by an irreversible act of amplification such as the blackening of a grain of silver bromide emulsion or the triggering of a photon-detector. . . . We are inescapably involved in bringing about that which appears to be happening."⁴⁶

According to F. Selleri, Wheeler is among the "most articulate and consistent of all Bohr's heirs," and so it is safe to take his pronouncements to be accurate interpretations and expansions of the genuine Copenhagen tradition.⁴⁷

The desire to avoid the specters of stark anti-realism and/or observer-created-reality entailed by the orthodox view has led some theoreticians to take even greater leaps

⁴⁴Roger Penrose, *The Emperor's New Mind: Concerning Computers, Minds, and the Laws of Physics* (Oxford: Oxford University Press, 1989), 226. Quentin Smith quotes Robert Pine, who in a manner similar to that of Penrose believes that the CI implies that quantum reality is created by human thought (observation). See Quentin Smith, "Why Cognitive Scientists Cannot Ignore Quantum Mechanics," in *Consciousness: New Philosophical Perspectives*, ed. Smith and Aleksandar Jokic (Oxford: Clarendon Press, 2003), 424.

⁴⁵John Archibald Wheeler, "Law without Law," in *Quantum Theory and Measurement*, ed. John Archibald Wheeler and Wojciech Hubert Zurek (Princeton: Princeton University Press, 1983), 184.

⁴⁶*Ibid.*, 184-85.

⁴⁷F. Selleri, "Wave-Particle Duality: Recent Proposals for the Detection of Empty Waves," in *Quantum Theory and Pictures of Reality: Foundations, Interpretations, and New Aspects*, ed. W. Schommers (New York: Springer-Verlag, 1989), 294-95. Herbert notes that Wheeler's Austin, Texas laboratory, the Institute of Theoretical Physics, is something of a "second Copenhagen." Herbert, *Quantum Reality*, 164. Indeed, Wheeler and his associates have turned out impressive work that continues the Copenhagen viewpoint.

into speculation. For instance, in 1957, Princeton graduate student Hugh Everett proposed that the measurement problem could be solved in the following way: whereas the standard view says the act of measurement instantiates one of the infinite possibilities for the quantum system, while ruling out all others as candidates for reality, Everett proposed that in fact all probabilities for quantum systems are realized, though all but one occur in parallel universes to which we have no access. This means there are an essentially infinite number of universes, all of them locked away from our detection by the fact that the quantum phenomena in *our* universe actualized a different probability. Everett dared to propose this “multi-verse” model because he found the Copenhagen view incoherent. How can the act of measurement decide between reality and unreality? But as David Lindley notes, all Everett has done is substitute one incoherent notion for another.⁴⁸ Importantly, Lindley goes on to point up the strategy for avoiding the conclusions of both the CI and Everett’s model. “If you want to believe that we live in only one universe after all, the way to avoid the unsettling implications of the Copenhagen interpretation is to deny that the indeterminacy of quantum mechanics is real. This was Einstein’s preference.”⁴⁹ I will argue in subsequent chapters that adherents to the Christian worldview ought to share the fundamentals of Einstein’s preference.

The sketch of reality given by the CI was very difficult for many of Bohr’s contemporaries to appreciate. In particular, Einstein and Erwin Schrödinger found Bohr, Heisenberg, and Pauli baffling and set out to turn the tide back toward realism by proposing thought-experiments that aimed to show the absurdity of the Copenhagen view. Ironically, to the extent that Einstein and Schrödinger succeeded in highlighting the CI’s absurdities, the physics world seemed all the more eager to champion Bohr and his band of

⁴⁸“The problem with Copenhagen is that it leaves measurement unexplained; how does a measurement select one outcome from many? Everett’s proposal keeps all outcomes alive, but this simply substitutes one problem for another: how does a measurement split apart parallel outcomes that were previously in intimate contact? In neither case is the physical mechanism of measurement accounted for; both employ sleight of hand at the crucial moment.” Lindley, *Weirdness*, 111.

⁴⁹Ibid.

revolutionaries.

Erwin Schrödinger's cat. In 1935, Erwin Schrödinger set out to win the physics world back to something like Newtonian sanity by discussing a crafty hypothetical scenario involving atomic radiation and a housecat. In specific, he aimed to confront the Copenhagen contentions that (a) the quantum system is in a superposition of all possible states before measurement, which means it has no determinate value if left to its own devices, and (b) that measurement of the system collapses the superposition (wavefunction) to a specific state. In his landmark encyclopedia on quantum physics, John Gribbin recounts Schrödinger's ploy very effectively.

The puzzle depends on setting up a system where there is a precise fifty-fifty chance of a particular quantum event – such as the decay of a radioactive nucleus – occurring. The conventional wisdom [i.e., the Copenhagen interpretation] in quantum mechanics says that the nucleus exists in a superposition of states, half decayed and half not decayed, unless its state is measured. Only at that point does it decide which state it is in. Schrödinger pointed out that the radioactive substance could be sealed in a windowless steel chamber . . . with a detector (perhaps a simple Geiger counter) to monitor it. The detector is wired up to release a cloud of poison gas into the room if the radioactive material decays, and living in the room there is the famous cat. If the chamber is sealed and nobody looks into it, then when the radioactive nucleus is in a fifty-fifty superposition of states, according to the strict Copenhagen interpretation the Geiger counter, the poison gas and the cat are all in a superposition of states. The radioactive material both has and has not decayed, and the poison gas both has and has not been released, and the cat both has and has not been killed. . . . [Assuming] the Copenhagen interpretation is correct, everything remains in limbo until an intelligent observer looks into the chamber. At that point, the superposition collapses and the cat becomes either dead or alive.⁵⁰

⁵⁰John Gribbin, *Q is for Quantum: An Encyclopedia of Particle Physics* (New York: Free Press, 1998), s.v. "Schrödinger's cat." James Cushing gives a more technical explanation of Schrödinger's cat paradox that is also helpful: "Schrödinger suggested coupling a microsystem (a 'uranium' nucleus or atoms) and a macrosystem (a live cat). Things are so arranged that, if the nucleus decays (with a characteristic lifetime τ_0), it triggers a device that kills the cat. . . . The point of the exercise now is to give a quantum-mechanical description of the time evolution of this coupled system. Let $\Psi(t)$ denote the wave function for the combined system, ϕ that for the cat, and ψ that for the atom. Then the initial state of the system is just

$$\Psi_0 = \Psi(t = 0) = \phi_{\text{live}} \psi_{\text{atom}}$$

This initial state evolves into

$$\Psi(t) = \alpha(t) \phi_{\text{live}} \psi_{\text{atom}} + \beta(t) \phi_{\text{dead}} \psi_{\text{decay}}$$

"As time goes on, things look less and less good for the cat's survival. *Before* we look at the system, $\Psi(t)$ represents a *superposition* of a live and a dead cat. *After* we look, the state function is reduced (live *or* dead). Schrödinger in effect posed the central question: What does $\Psi(t)$ represent? Possible answers

Naturally, this experiment has never been carried out on a live cat and it would be pointless to do so. Seemingly, it is enough just to mull the hypothetical scenario over long enough to grasp its paradoxical ending. Schrödinger was sure this would spell the end of Copenhagen excesses, but in fact, it seems to have enshrined them instead. The cat paradox is regularly celebrated as a “strange-but-true” signal of just how odd the quantum world really is.⁵¹

The EPR experiment. Albert Einstein was a man under siege throughout the second quarter of the twentieth century. On the one hand, he was in the grip of unparalleled popularity. His breakthroughs in relativity theory were so astounding and far-reaching that journalists, scientists, and literary figures from around the world hounded him for input on all manner of topics. He became the chief savant for his era, and his diverse pronouncements and quips are a fixture in everything from textbooks to postcards even in our day. On the other hand, a growing number of physicists clamored for Einstein to follow the quantum evidence and rejoin the revolution he had helped start. Einstein, it turns out, did not like what was going on in Bohr’s Copenhagen laboratories. While the physics crowd was going after quantum oddities, Einstein stubbornly beat the old-world drum trying to call everyone back to causality, locality, and the host of suddenly unfashionable presuppositions by which science had grown from the ground up. As George Musser has said, Einstein digressed, in popular physics lore at least, from the originator of some of quantum theory’s most important insights to “the quantum’s deadbeat dad.”⁵²

are: (a) *our state* of knowledge (quantum mechanics is incomplete) and (b) the *actual state* of the system (there is a sudden change upon observation). If we choose (a) (which is what Schrödinger feels we *must* do intuitively), then quantum mechanics is *incomplete* (i.e., there are physically meaningful questions about the system that it cannot answer—*surely* the cat was *either* alive *or* dead *before* we looked). On the other hand, choice (b) saddles us with the measurement problem (and with a vengeance). The collapse of the wave function becomes an actual *physical* process that must be explained.” See Cushing, *Quantum Mechanics*, 38-39.

⁵¹Norris notes this in Christopher Norris, “Critical Realism and Quantum Mechanics: Some Introductory Bearings,” in *After Postmodernism: An Introduction to Critical Realism*, ed. José López and Garry Potter (New York: The Athlone Press, 2001), 125.

⁵²George Musser, “Was Einstein Right?” *Scientific American* 291 (September 2004): 88. Similarly, John Polkinghorne seems gently to chide Einstein when he calls him “the last of the great ancients

Einstein's fall-out with quantum theory began around 1920 when he shifted away from his youthful exuberance for positivist ideals to a thoroughgoing realism.⁵³ For the new Einstein, the concepts of causality and observer-independence were fundamental to any respectable brand of realism.⁵⁴ Having adopted these, and having shown his colors for more than a decade, Einstein in 1935 took the battle to the heart of the orthodox view by teaming up with two young colleagues (Boris Podolsky and Nathan Rosen) to produce one of the most notable thought-experiments in the history of science.⁵⁵ Their experiment is commonly called "EPR" or "EPR paradox" in reference to their last names.

To begin with, EPR sought to counter the Copenhagen completeness claim by defining "completeness" in such a way that clearly ruled out the orthodox party's pretensions. It is required of a "complete theory," said EPR, that "every element of the physical reality must have a counterpart in the physical theory."⁵⁶ Hence, a theory is incomplete if some aspect of the reality it seeks to describe is left unmentioned. EPR define reality in the following way:

The elements of the physical reality cannot be determined by *a priori* philosophical considerations, but must be found by an appeal to results of experiments and measurements. A comprehensive definition of reality is, however, unnecessary for our purpose. We shall be satisfied with the following criterion, which we regard as reasonable. *If, without in any way disturbing a system, we can predict with certainty (i.e., with probability equal to unity) the value of a physical quantity, then there exists an element of physical reality corresponding to this physical quantity.*⁵⁷

rather than the first of the great moderns." See John Polkinghorne, *Science and Providence: God's Interaction with the World* (Boston: Shambhala Publications, 1989), 78.

⁵³ Arthur Fine, "The Natural Ontological Attitude," in *Scientific Realism*, ed. Jarrett Leplin (Los Angeles: University of California Press, 1984), 92; Norris, *Flight*, 8.

⁵⁴ Arthur Fine, *The Shaky Game: Einstein, Realism and the Quantum Theory* (Chicago: University of Chicago Press, 1986), 103.

⁵⁵ Actually, the EPR experiment is more about the *philosophy* of physics than anything else. In Max Jammer's words, "Being a study of the completeness of a physical theory, the EPR paper belongs, strictly speaking, to the meta-theory or philosophy of physics rather than to physics proper." Max Jammer, "The EPR Problem in its Historical Development," in *Symposium on the Foundations of Modern Physics: 50 Years of the Einstein-Podolsky-Rosen Gedankenexperiment*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific Publishing, 1985), 130.

⁵⁶ A. Einstein, B. Podolsky and N. Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 47 (1935): 777.

⁵⁷ *Ibid.*

This means that the ability to formulate accurate predictions indicates that some underlying physical reality exists and determines outcomes, and that an adequate theory will account for said reality. If a theory fails in this regard, and EPR maintains that quantum theory does, then the theory is not satisfactory.

The EPR experiment as described in the original paper is difficult to follow, but its essence can be described in the following way.⁵⁸ Imagine two quantum particles, which I shall call E and F , that interact while in close proximity to one another, thus forming a quantum system, EF . At the time of their interaction, the momentum of EF is measured. Immediately after this, the two particles are forced to disengage from one another and are moved off in opposite directions. It is key that as they hurtle away from each other they are not to interact with anything else, for interaction with any “new” particle or particles would effectively erase the history the original pair of particles shared, thus dismantling EF . Due to conservation of momentum, the separated particles will still display a total momentum value that is identical to that which was measured when the particles formed the immediate system. Thus, if the total momentum value was 1 when the particles interacted, it should be possible to add the separate values for momentum when the particles are widely separated and still reach 1 as the total momentum for the now widely separated EF . For instance, if particle E has value .45, its now distant companion, F , will necessarily have a value of .65, for a conservation of the total value of 1 for system EF . It is important to understand that in this example, the .65 value for F is obtained by deduction rather than empirical measurement.

As per the Uncertainty Principle, when the momentum of E is measured all information about its *position* is lost.⁵⁹ EPR tries to overcome this difficulty in the following way: if you measure the momentum of E , you will have forfeited information on its

⁵⁸The essence of the experiment is the same in all explanations, but the specific manner in which it is illustrated differs widely. My way of illustrating EPR resembles the approach Gribbin takes in his encyclopedia, but I diverge from him at key points. See Gribbin, *Encyclopedia*, s.v. “EPR experiment.”

⁵⁹Recall that the Uncertainty Principle says it is impossible to know simultaneously both the position and momentum of a quantum particle.

position. Nevertheless, this information can be regained if the experimenter chooses to measure the position of F and at the same time measure the momentum of E . By deduction from the conservation law, she can then figure (not measure) the momentum and position for F and E respectively. Hence, both the position and momentum can simultaneously be known for quantum particles E and F , and the Uncertainty Principle is overturned.

Now, here's where the rub comes in. On the Copenhagen view, the act of observation forces the quantum system EF to cough up some determinate values, values it did not possess prior to observation. But in that case, measuring the momentum for E must "create" the anti-correlated value in F , such that EF retains its original momentum value. Problem is, E and F are now too widely separated for causal interaction. Thus, the experiment forces the experimenter to make one of two conclusions: either E and F each have momentum values prior to measurement, such that the experimenter has only "discovered" their values via the measurement procedure outlined above, or else she must conclude, with the Copenhagen theorists, that the value for E was created by measurement, and that this immediately "caused" F to have the anti-correlated value. The problem with this latter option is that it violates locality, and this is really the main point EPR is putting over on the Copenhagen camp.⁶⁰ How can measuring E affect F when the two are too widely separated to interact. For Einstein, this was "spooky action-at-a-distance," a plot more fitting for ghost stories than physics. In fact, EPR's argument that quantum theory itself is incomplete hinges on the impossibility of this sort of anomalous action. As John Bell explains,

Could it be that the first observation somehow fixes what was unfixed, or makes real what was unreal, not only for the near particle but also for the remote one? For

⁶⁰Norris, *Flight*, 20. Alastair I. M. Rae is also helpful on this point. "If it is inconceivable that this measurement could have interfered with the distant object, it follows that the first photon must have possessed the measured property *before* the measurement was carried out. As the property measured can be varied by the experimenter adjusting the distant apparatus, EPR concluded that all physical properties . . . must be 'real' *before* they are measured, in direct contradiction to the Copenhagen interpretation." Alastair I. M. Rae, *Quantum Physics: Illusion or Reality?* (Cambridge: Cambridge University Press, 1986), 50-51.

EPR that would be an unthinkable ‘spooky action at a distance’. To avoid such action at a distance they have to attribute, to the space-time regions in question, *real* properties in advance of observation, correlated properties, which *predetermine* the outcomes of these particular observations. Since these real properties, fixed in advance of observation, are not contained in quantum formalism, that formalism for EPR is *incomplete*. It may be correct, as far as it goes, but the usual quantum formalism cannot be the whole story.⁶¹

Hence, EPR indicates that the quantum theory is vitally incomplete, or else the absurdities of non-locality and observer-created reality are true facts of the universe. Copenhagen theorists embrace these very absurdities, and thus neutralize the albatross that EPR fashions for them.

The EPR paper had a “remarkable” impact on Bohr. As his colleague, Léon Rosenfeld, tells it, the paper descended on Bohr like “a bolt from the blue,” and prompted Bohr to enlist Rosenfeld’s aid in a day-and-night operation to rebut Einstein and company.⁶² For all the frenetic energy EPR seems to have elicited from Bohr, he apparently did not find the paper all that threatening to his own position. His published response dismisses EPR on, among other things, the counts that its wording about measuring “without disturbing the system” is ambiguous and that the experimental set-up itself calls into doubt the possibility of precise measurement.⁶³ In fact, Bohr thought EPR unintentionally provided the greatest evidence yet for the need to abandon classical views in favor of the Copenhagen reading.⁶⁴ Commentators typically agree with Bohr on this point. “The EPR argument backfired. It was invented to demonstrate the shortcomings of the orthodox Copenhagen interpretation of quantum theory. It only ended up by showing an additional difficulty that an alternative theory describing reality would have to face. It

⁶¹John Bell, “Bertlmann’s Socks and the Nature of Reality,” in *Speakable and Unsayable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 143.

⁶²From Mara Beller and Arthur Fine, “Bohr’s Response to EPR,” in *Niels Bohr and Contemporary Philosophy*, ed. Jan Faye and Henry J. Folse (Boston: Kluwer Academic, 1994), 1.

⁶³Niels Bohr, “Can Quantum-Mechanical Description of Physical Reality be Considered Complete?” *Physical Review* 48 (1935): 700.

⁶⁴Norris, *Flight*, 12-13.

would have to include faster-than-light influences.”⁶⁵

Beller adds to this the observation that the EPR paper expressed naïve varieties of realism and correspondence.⁶⁶ Bohr, as one of the most rhetorically and philosophically astute physicists of the modern era, was able to seize on such weaknesses and cash them out in favor of his program. Ironically, however, Bohr’s rebuttal is not very substantial when closely examined. Beller credits Bohr for scoring points with “a few ingenious rhetorical moves,” but on the whole finds his response unsubstantial.⁶⁷ Importantly, Bohr’s response boils down to an appeal from positivism, which contrasts sharply with EPR’s straightforward realist stance. Philipp Frank closely examined EPR and Bohr’s response and concluded that the contention between them was essentially philosophical: classical metaphysical versus positivistic conceptions of the logic of science.

According to Frank, the metaphysical outlook, that of Einstein and Planck, recognizes three components of a physical theory: (1) the reading of the measuring instruments, (2) the mathematical formalism, and (3) physical reality. The positivistic approach simply dispenses with (3). Evidently, writes Frank, Bohr shares this positivistic approach.⁶⁸

Bohr confirmed Frank’s conclusions in personal correspondence, and from 1935 onward Bohr’s utterances generally matched the positivist outlook very closely.⁶⁹ That Bohr’s response to EPR was so highly touted indicates something of the popularity to which the positivist framework had risen by the 1930s. Together, the new physics and

⁶⁵P. H. Eberhard, “The EPR Paradox: Roots and Ramifications,” in *Quantum Theory and Pictures of Reality: Foundations, Interpretations, and New Aspects*, ed. W. Schommers (New York: Springer-Verlag, 1989), 57.

⁶⁶Beller, *Quantum Dialogue*, 154.

⁶⁷“It is bewildering that Bohr’s response was ever considered, and is often still considered, an adequate (not to mention ‘triumphant’!) reply to EPR. I can suggest a few explanations for this strange state of affairs. The myth is in part connected with the general mythology of the Copenhagen interpretation, the hero worship of Bohr, the fabrication of the ‘winner’s narrative’ A few ingenious rhetorical moves characterize Bohr’s response and create the illusion of victory. By giving a short, nonmathematical summary of the dense and complex EPR paper, Bohr ensured that few would bother to read the EPR paper itself.” *Ibid.*, 153.

⁶⁸Beller and Fine, “Bohr’s Response,” 19.

⁶⁹*Ibid.*, 20, 30.

the new philosophy of science were pulling the supports out from under traditionalists like Einstein.

Bell, EPR, and non-locality. The easy majority of theoretical physicists sided with Bohr against EPR, but so long as the EPR experiment was merely hypothetical the matter could not be settled by laboratory trial. John Bell, following suggestions laid down by famous Copenhagen antagonist David Bohm, elucidated the first steps toward rectifying this shortfall by developing what is known as Bell's Theorem.⁷⁰ The technical aspects of Bell's proposal are beyond the reach of this present study.⁷¹ In short, Bell described an experiment that would test whether or not Copenhagen's non-locality claim is correct. Bell held out hope of vindicating Einstein in this matter, but when Bell's Theorem was finally put to the test in the laboratory the CI's insistence on genuine non-locality in quantum systems was by all appearances vindicated. First in 1981, and then again a year later, a team of French physicists presented strong evidence for quantum non-locality.⁷²

⁷⁰Bohm actually suggested a *variation* of EPR that nonetheless kept with its aims. In 1964, Bell described how Bohm's modified thought-experiment could actually be carried out under laboratory conditions if the measuring capacities of the relevant equipment were greatly improved, which he doubted was possible. As it turns out, the necessary advancements in technology came less than twenty years after Bell introduced his theorem.

⁷¹The interested reader may find Richard Kitchener's fairly technical explanation helpful. "Bell proposed a way of testing the claim of nonlocality by carrying out the EPR experiment. As before, two twin paired-polarized protons are sent out in opposite directions and their polarization is measured. The angle of polarization α can be changed from 0° to 90° . If both angles of polarization are 0° , then we expect a perfect correlation between the measurements of the two particles. If the angle α is 90° , we expect a lack of correlation, and if α is somewhere in between, say 45° , we expect a correlation in between these two figures and, therefore, a certain amount of error $E(\alpha)$. Now suppose one rotates one polarizer 45° to the right and the other polarizer 45° to the left. What would we expect? If there are no nonlocal effects, we would expect the resulting frequency of errors $E(2\alpha)$ to be twice that of $E(\alpha)$: $2E(\alpha)$. (Since the error should actually be somewhat less than this, we can say $E(2\alpha) \leq 2E(\alpha)$.) This is called *Bell's inequality*, and the argument concerning it is called *Bell's Theorem*. When experiments are performed...this inequality is considerably violated and $E(\alpha) > 2E(\infty)$. Because there is a much higher correlation between the two particles than one could reasonably expect, we conclude that locality is violated. Hence, a local hidden variable approach is disconfirmed (since one of its predictions is falsified) whereas the Copenhagen interpretation is confirmed (since they correctly predict this result). Hence, *if there is a reality independent of and underlying quantum phenomena (hidden variables), this reality must be nonlocal.*" Richard F. Kitchener, "Introduction: The World View of Contemporary Physics: Does It Need a New Metaphysics?" in *The World View of Contemporary Physics: Does it Need a New Metaphysics?* ed. Richard F. Kitchener (Albany: State University of New York Press, 1988), 13.

⁷²In their 1981 report, Alain Aspect, Philippe Grangier, and Gérard Roger reported that their results were "to a high statistical accuracy a strong evidence against the whole class of realistic local theories." Alain Aspect, Philippe Grangier, and Gérard Roger, "Experimental Tests of Realistic Local Theories via Bell's Theorem," *Physical Review Letters* 47 (1981): 463. Further tests proved to be even more definitive, as detailed in their 1982 report: Alain Aspect, Philippe Grangier, and Gérard Roger, "Experimental Realization of Einstein-Podolsky-Rosen-Bohm *Gedankenexperiment*: A New Violation of Bell's Inequal-

By 1997, tests showed that entangled quantum particles separated by eleven kilometers retain their linkage, as if they were immediately present to one another. As Brian Greene explains, 11 kilometers is an impressive distance on the human scale, but on the micro-physical scale it is absolutely gargantuan. In this light, we have reason to suppose the correlations will hold no matter how widely we separate the entangled particles.⁷³

Might locality be recovered in future experiments? Bell acknowledges that even the best of experiments fall short of the ideal conditions of the EPR *gedanken*-experiment, but doubts this deficiency is enough to recover locality at any future date.⁷⁴ Hence, most theorists doubt that any hope remains for attributing non-locality to incompleteness in quantum theory.

Non-locality is difficult to explain, let alone embrace even for those who find it inevitable.⁷⁵ The multi-verse model presented by Everett avoids non-locality but in a

ities,” *Physical Review Letters* 49 (1982): 91-94. For a reasonably clear explanation of the Aspect experiments, see Gribbin, *Encyclopedia*, s.v. “Aspect experiment.”

⁷³Greene, *Fabric*, 115.

⁷⁴“The actual experiments [that prove non-locality] depart too far from the ideal, and only after the various deficiencies are ‘corrected’ by theoretical extrapolation do the actual experiments become critical. There is a school of thought which stresses this fact, and advocates the idea that better experiments may contradict quantum mechanics and vindicate locality. I do not myself entertain that hope. I am too impressed by the quantitative success of quantum mechanics, for the experiments already done, to hope that it will fail for more nearly ideal ones.” From John Bell, “La Nouvelle Cuisine,” in *Speakable and Unspeakeable in Quantum Mechanics: Collected Papers on Quantum Philosophy*, 2nd ed. (Cambridge: Cambridge University Press, 2004), 245. Elsewhere, Bell says real-life experiments fall short of the EPR standards due to the difficulty of accurately counting quantum particles. Though he describes the process as “very inefficient,” he still maintains it is unlikely that non-locality will be overturned. John Bell, “Atomic-cascade photons and quantum-mechanical nonlocality,” in *Speakable and Unspeakeable in Quantum Mechanics: Collected Papers on Quantum Philosophy*, 2nd ed. (Cambridge: Cambridge University Press, 2004), 109. The appeal to inefficiency may have become even less tenable in 2001 with the work of M. A. Rowe et al., which narrowed the detection inefficiency to near zero. M. A. Rowe et al., “Experimental Violation of a Bell’s Inequality with Efficient Detection,” in *Nature* 409 (2001): 791-94. However, the measurements did not include the condition so vital to proving non-locality, namely, the wide separation of particles. An experiment incorporating that condition and proving high detection efficiency has yet to be performed. See Alain Aspect, “Introduction: John Bell and the Second Quantum Revolution,” in *Speakable and Unspeakeable in Quantum Mechanics: Collected Papers on Quantum Philosophy* (Cambridge: Cambridge University Press, 2004), xxv.

⁷⁵Michael Redhead has non-locality in view when he says, “Quantum mechanics has landed some pretty queer fish.” David Mermin says anyone not bothered by the results from Bell’s Theorem “has to have rocks in his head.” See respectively, Michael Redhead, *Incompleteness, Nonlocality, and Realism: A Prolegomenon to the Philosophy of Quantum Mechanics* (Oxford: Clarendon Press, 1987), 169; David Mermin, “Is the Moon Really there When Nobody Looks? Reality and the Quantum Theory,” *Physics Today* 38 (April 1985): 41.

manner that is too incredible.⁷⁶ While one cannot help but feel the weight of current evidence, I suggest it is possible to be rational and yet hold out hope that non-locality will someday be revised or supplemented in such a way as to lessen the present difficulty.

Wesley Salmon stakes a similar claim.

The situation, basically, is this. There are impressive remote correlations in the spin-states of photons that cannot be explained by local causal principles; action-at-a-distance appears to be manifested. The results can be derived from spin conservation, but it is nonlocal conservation, and we have no mechanism by which to explain it. I have no idea what an appropriate explanation would look like; we may need to know more about the microsystem before any explanation can be forthcoming. But I do have a profound sense that *something* that has not been explained needs to be explained.⁷⁷

The history of science indicates that we have good reason to side with Salmon on this matter. As I will show later, scientists of past generations have taken the appearance of distant action to be a sign that some variety of local causal agency exists but is presently unknown. In other words, action-at-a-distance indicates that scientists have more work to do before the true facts of the situation can be described.

Classical Language and Completeness

Another key aspect of Bohr's approach to quantum mechanics was his insistence that though classical concepts are inapplicable in microphysics, classical language must be retained when describing quantum phenomena.⁷⁸ This emphasis on the retention of classical language serves to heighten the sense of paradox in quantum theory, as for instance when Copenhagen theorists retain such terms as "particle" and "wave" to describe quantum systems that, on their view, fit neither bill in any traditional, cognizable sense. This practice runs counter to the realist desire to rule out paradox by incorporating

⁷⁶David Z. Albert, "Bohm's Alternative to Quantum Mechanics," *Scientific American* 270 (May 1994): 67.

⁷⁷Wesley C. Salmon, *Four Decades of Scientific Explanation* (Minneapolis: University of Minnesota Press, 1989), 186.

⁷⁸Niels Bohr, "Causality and Complementarity," *Philosophy of Science* 4 (1937): 294. Heisenberg agreed with Bohr. See Heisenberg, *Physics and Philosophy*, 44.

new terms for discoveries that cannot properly be encompassed by traditional terminology. For instance, Louis de Broglie and David Bohm favor ditching the Copenhagen paradox regarding wave-particle duality, by which it is said both “wave” and “particle” paradoxically apply to quantum entities, by simply saying quantum entities are something like “waves and particles” in a way that is not genuinely paradoxical, though we cannot now see clearly enough to say how this is so.⁷⁹ The realist approach insists that it is our inchoate understanding rather than nature itself that gives rise to paradox in quantum theory.

The emphasis on classical language is a component of the orthodox theory’s claim that quantum theory is complete, such that no further elucidations will overturn the quantum paradoxes. To the extent that physicists and philosophers buy into this claim, the debate about whether or not Copenhagen has cornered the market on quantum analysis is closed. Grometstein explains one argument Copenhagen theorists put forth in defense of their completeness claim. The argument is over whether or not a vital equation (the S-equation) used to describe quantum probabilities is a complete description of a quantum system. As you will see, the essence of the “argument” is largely based on putting forth a presupposition that conflicts with a vital realist presupposition.

Criticism leveled against the S-equation by Einstein and others [of realist persuasion] did not touch its accuracy but its completeness. The critics insisted that the equation must be incomplete if it cannot tell you where an individual electron is to be found, but only the distribution of electrons observed over many repetitions of a measurement. This being so (they said), the equation should be augmented in such a way as to provide predictions about individual electrons. The orthodox interpretation of quantum mechanics (the *Copenhagen Interpretation*) holds that no augmentation is possible because the individual electron does not possess the quality of ‘position’ before it is measured. It acquires a ‘position’ only when you detect it. Hence, the S-equation is not incomplete. Not so, insist the critics: the electron has a position but it is not accounted for by the S-equation, which is therefore defective; the equation *is* incomplete and must be corrected.⁸⁰

⁷⁹John Bell, “Speakable and Unsayable in Quantum Mechanics,” in *Speakable and Unsayable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 171.

⁸⁰Grometstein, *Roots*, 382. See also Dipankar Home, *Conceptual Foundations of Quantum Physics: An Overview from Modern Perspectives* (New York: Plenum Press, 1997), 16.

Hence, on the CI, the conclusion that the S-equation is a complete description of the quantum system is an entailment of the presupposition that quantum particles do not have values prior to measurement. The emphasis on the Uncertainty Principle also plays a significant role in the orthodox argument for completeness. Plotnitsky explains this helpfully.

As [Bohr] showed, the experimental arrangements necessary for controlling the indeterminacy in measuring one conjugate variable with unlimited precision . . . would entail renouncing the possibility of controlling the indeterminacy in measuring the other variable. Once we control the indeterminacy in measuring one complementary variable . . . we unavoidably lose our physical means of controlling the indeterminacy in measuring the other, and there is no way to circumvent this mutual exclusivity. Hence quantum mechanics must be seen, according to Bohr, as a *complete* description, as complete as it can be, given quantum conditions [as described by Heisenberg's Uncertainty Principle]. In classical terms, the picture is incomplete, and uncertainty relations may be said to measure this incompleteness. According to Bohr, however, they signal the ultimate inapplicability to quantum mechanics of a classical-like interpretation⁸¹

Heisenberg himself understood the ramifications of his Uncertainty Principle along exactly these lines. Decades before Thomas Kuhn would write about the incommensurability of scientific paradigms, Heisenberg claimed the quantum theory was a closed theory, the modification of which would destroy it entirely.⁸² Hence, quantum theory, as described by the reigning Copenhagen paradigm, is inviolate.

The chief result of the claim that quantum theory is closed is that the search for “hidden variables” is useless. Hidden variables are just that, variables that are currently hidden from us in that we currently have no conceptual clarity or empirical proof for their existence. On the realist view, there must surely be hidden variables operative in quantum operations—factors that, if we knew them in detail, would explain away the appearance

⁸¹Plotnitsky, “Complementarity,” 156-57.

⁸²Heisenberg, *Physics and Philosophy*, 94. Beller finds many parallels between Kuhn and Heisenberg, especially in Heisenberg's use of the “closed theory” concept to insure acceptance of the CI. “The notion of a closed theory is also ingeniously constructed to argue for the inevitability and finality of quantum theory and to encourage uncritical commitment by its practitioners, very much like the Kuhnian paradigm.” From Beller, *Quantum Dialogue*, 289. Near the end of his life, Heisenberg was prompted by C. F. von Weizsäcker to read Kuhn's work. He did so, and concluded that Kuhn's use of “paradigm” was identical to his own use of “closed theory.” See C. F. von Weizsäcker, “Heisenberg's Philosophy,” in *Symposium on the Foundations of Modern Physics 1987: The Copenhagen Interpretation 60 Years After the Como Lecture*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific, 1987), 281.

of such things as acausality and possibly even non-locality. In essence, then, he who appeals to hidden variables to escape such paradoxes is making that claim that the current quantum theory is *incomplete*. This is the contention of all alternatives to the CI, from Einstein forward. Heisenberg quotes Bohr as having compared this hope to the following mathematical folly: “We may hope that it will later turn out that sometimes $2 \times 2 = 5$, for this would be of great advantage to our finances.”⁸³ If consensus opinion backed Bohr on this matter half a century ago, it does so even more roundly today in light of the impressive experiments that seemingly prove non-locality.

[The] fog that permeates the quantum world can never go away. There are no ‘hidden variables,’ which, if known, would increase our precision beyond the natural limit that rules the quantum world. The uncertainty, the fuzziness, the probabilities, the dispersion simply cannot go away—these mysterious, ambiguous, veiled elements are an integral part of this wonderland.⁸⁴

A final reason so many physicists and philosophers came to believe in the impossibility of hidden variables is because John von Neumann was thought to have proven their impossibility mathematically. With Heisenberg, von Neumann claimed that the attempt to add hidden variables to quantum mechanics would bring the whole theory crashing down.⁸⁵ Once von Neumann’s mathematical proof was accepted as valid, those who hoped to pull Copenhagen down with cords woven from hidden variables appeared to be flying in the face of mathematical certainty.

⁸³Werner Heisenberg, “The Development of the Interpretation of the Quantum Theory,” in *Niels Bohr and the Development of Physics*, ed. W. Pauli (New York: McGraw-Hill, 1955), 18.

⁸⁴Amir D. Aczel, *Entanglement: The Greatest Mystery in Physics* (New York: Four Walls Eight Windows, 2002), xi. See also Max Tegmark and John Archibald Wheeler, “100 Years of Quantum Mysteries,” *Scientific American* 284 (February 2001): 72. Jon Jarrett believes it is still logically possible that hidden variables exist, but thinks no respectable realist will carry on arguing for them. “Yes, it is logically possible that in each of the several different actual Bell-type experiments, there were unknown hidden connections, perfectly ‘local realistic’ in character, which brought about a correlation in the distribution of initial two-particle states and the premeasurement detector-states in just such a way so as to yield the observed quantum statistics. . . . In the absence of any independent justification, the hypothesis of such a diabolical conspiracy of nature is surely so blatantly *ad hoc* that no self-respecting local realist could entertain it seriously. . . . Conspiratorial mechanisms of various sorts have been proposed (under other descriptions, of course), and these approaches deserve consideration, but I fail to see any suitably independent justification for taking them seriously at the present time.” Jon Jarrett, “Bell’s Theorem: A Guide to the Implications,” in *Philosophical Consequences of Quantum Theory: Reflections on Bell’s Theorem*, ed. James T. Cushing and Ernan McMullin (Notre Dame: University of Notre Dame Press, 1989), 76.

⁸⁵Von Neumann, *Mathematical Foundations*, 324-25.

If no hidden variables are possible, realism as we have known it is clearly inapplicable. “Local realism requires that the laws which govern physical interactions and the evolution of physical states, while they need not be deterministic, must respect considerations of what is commonly called ‘locality’; roughly speaking, ‘action-at-a-distance,’ in some suitable sense of that phrase, is prohibited.”⁸⁶

So, do Copenhagen theorists adopt non-local realism or outright anti-realism? Are they positivists, instrumentalists, or operationalists? Answers differ depending on which theorist is in view, and individual theorists are often blatantly inconsistent.⁸⁷ I will address these important issues in the philosophy of science more closely in the next chapter.

Irrationality

The Copenhagen emphases on genuine indeterminacy and acausality in the quantum realm, and especially the insistence that acts of observation (measurement) *create* objective quantum values and possibly the quantum entities themselves, forge a fundamentally irrational concept of nature. K. V. Laurikainen, an expert on the life and works of Copenhagen theorist Wolfgang Pauli, provides ample justification for this claim and indicates how the orthodox view relates to traditional Western presuppositions.

The conception of reality underlying the Copenhagen Interpretation is still a problem. The reason for this is the *repression of the irrational* characteristic of Western thought. Wolfgang Pauli was the most radical but also the most consistent among the founding fathers of quantum theory. His conception of reality opens up a new perspective for science: a view into an *irrational world*. If we take Pauli’s remarks seriously, we must evaluate many important questions in new light.⁸⁸

⁸⁶Jarrett, “Bell’s Theorem,” 62.

⁸⁷“Strong realistic and positivist strands are present in the writings of the founders of the quantum revolution—Bohr, Heisenberg, Pauli, and Born. Militant positivist declarations are often followed by fervent denials of adherence to positivism. No wonder different scholars, with good textual evidence, have arrived at conflicting interpretations of these writings.” Beller, *Quantum Dialogue*, 172.

⁸⁸K. V. Laurikainen, “Wolfgang Pauli’s Conception of Reality,” in *Symposium on the Foundations of Modern Physics: The Copenhagen Interpretation 60 years After the Como Lecture*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific Publishing, 1987), 209.

Pauli was especially convinced that the Copenhagen emphasis on the indeterminism of quantum systems indicated that rational theories provide only approximate models for a reality that is fundamentally *irrational*.⁸⁹ Extending his purview past Pauli and into the Copenhagen view generally, Laurikainen says the reduction in state the quantum system supposedly undergoes when measured is another aspect of genuine irrationality because no one can provide a rational explanation for how it can be this way.⁹⁰

Conclusion

The reader is now perhaps better able to perceive the distinctive features of the Copenhagen interpretation and understand how they fit with quantum science. Repeating the list given in chapter 1, a sample of components vital to the CI includes the following: (1) the quantum theory, as developed by roughly 1930 and not since altered, is as complete a description of quantum phenomena as is possible, which entails, (2) that indeterminism is genuinely a characteristic of quantum events and not merely a reflection of current theoretical and investigative limitations, (3) that quantum acausality is one consequence of this indeterminacy, (4) that wave-particle duality is a complete description of a quantum system, such that wave and particle characteristics are said to be “complementary,” which on Bohr’s terms means quantum nature is properly described as paradoxical, and (5) that quantum systems remain indeterminate (undecided on such factors as wave or particle behavior, position and momentum values) until they are observed either by a conscious being or measuring apparatus.

By the end of 1927, Bohr and colleagues had established the clear supremacy of their Copenhagen interpretation for quantum physics. In fact, the CI would rise to such unanimity that several key figures in science and philosophy of science refused to call it

⁸⁹Ibid., 214.

⁹⁰K. V. Laurikainen, “Quantum Theory and the Problem of Free Will,” in *Symposium on the Foundations of Modern Physics 1990: Quantum Theory of Measurement and Related Philosophical Problems*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific, 1991), 216.

the “Copenhagen interpretation.” Richard Healey notes that distinguished physicist Sir Rudolf Peierls found the term objectionable because it implied there was more than one interpretation of quantum mechanics.

There is only one. There is only one way in which you can understand quantum mechanics. There are a number of people who are unhappy about this, and are trying to find something else. But nobody else has found anything which is consistent yet, so when you refer to the Copenhagen interpretation of the mechanics what you really mean is quantum mechanics.⁹¹

As recently as 1992, a notable scholar reviewed the history of interpretive options in quantum physics and announced that there are no serious alternatives to the Copenhagen view.⁹² Thus, from 1927 to our own day, the CI has essentially been the only sanctioned interpretation of quantum mechanics. It is the view of the textbooks, the position espoused in the lecture halls, and the interpretation that is discussed at the conferences and in the journals. A great many physicists are virtually or actually ignorant of the fact that alternatives exist to the CI, let alone that at least one of them is empirically equivalent to it while retaining more of the classical components of Western views about the natural world. While most physicists expressly ignore interpretational issues in quantum physics, those that do cast an eye in that direction see quantum mechanics as proof that either traditional worldviews or quantum theory itself must be overhauled. As for philosophers who examine the situation in quantum mechanics, they are more evenly divided, in recent times at least. Some pitch a sale for new ways of construing the world—ways that are significantly informed by the CI. Others, the *realists*, bid us all hold the CI in abeyance as we await the elucidation of current quantum mysteries. I count myself a member of this latter group. As I will argue below, there are compelling reasons to expect the CI to pass from favor at a future date. First, however, I will review some of the im-

⁹¹Peierls quoted in Richard Healey, *The Philosophy of Quantum Mechanics: An Interactive Interpretation* (New York: Cambridge University Press, 1989), 1-2.

⁹²Roland Omnès, “Consistent Interpretations of Quantum Mechanics,” *Reviews of Modern Physics* 64 (1992): 340.

portant applications thoughtful persons have made of the CI. This is the task of the next two chapters.

CHAPTER 3

APPLICATIONS OF THE COPENHAGEN INTERPRETATION IN SOCIOLOGY, PHILOSOPHY, AND SCIENCE

To the extent that the Copenhagen interpretation is thought to be an accurate reflection of truth about the physical universe it is only fitting that attentive persons would seek to make applications of this truth in fields other than physics. This is especially so in an era dominated by naturalistic science. After all, if the microphysical world is really the way the CI says it is, and the macrophysical world is but an aggregation of micro-entities, it seems inevitable that quantum reality will ascribe tangible values to the things built from it. Arkady Plotnitsky, for instance, seeks to make applications of Bohr's complementarity doctrine in the humanities and the social sciences, and foresees that applications will extend to "entire theoretical matrices or fields."¹ Physicist John Wheeler is also confident that complementarity, perhaps the most significant of the Copenhagen doctrines, ought comprehensively to shape our view of the world.

The idea of complementarity . . . is evidently appropriate for use in every field of thought. Indeed, as application after application comes up, one discovers in how many situations there is no reasonable alternative to the language of complementarity. One can never relinquish possession of this new means to think and speak clearly. To me, the most miraculous part of it all is man's ability to discover this one kind of limit on what man can ever know!²

In this chapter, I trace noteworthy applications of the orthodox interpretation of quantum physics in sociology, philosophy, and science, with a view toward demonstrat-

¹Arkady Plotnitski, *Complementarity: Anti-Epistemology after Bohr and Derrida* (Durham, NC: Duke University Press, 1994), 73-74.

²John Archibald Wheeler, *At Home in the Universe* (Woodbury, NY: American Institute of Physics, 1994), 19.

ing that the CI is being used as a template, whether solely or in conjunction with other templates, for worldview construction.

Applications in Sociology

Business and Leadership

For several decades now, Wall Street and many other financial centers and institutions around the world have regularly hired quantum physicists to work alongside employees whose training is more traditional to the financial sector. Known as “quants,” these physicists use the “classic tools of twentieth-century divination” (quantum mechanics and relativity theory) to gain an upper hand on market analysis.³ Kirill Ilinski compares market fluctuations to quantum variability, and by this thinks he has insight on how to classify market numbers.⁴ He especially relies on the application of quantum uncertainty to uncertainties in the social and natural sciences, though he recognizes certain limitations to this approach.

According to the philosophy prevailing among physicists, quantum uncertainty is a fundamental law of nature. The laws of the microworld are fundamentally different from what we observe in our everyday life and describe in common terms. The peculiarities of quantum physics are just the price that we pay for our inability to think in a ‘quantum’ manner. This view suggests that the uncertainty cannot be removed or reduced by any improvement in measurement technique or any technological means, including even the use of currently unknown ‘fine’ fields. This statement is much stronger than just the technological impossibility of accurate measurements, and gave birth to the language of non-commutative operators in the theory of quantum phenomena. Thus the uncertainties in the social and natural sciences can both be considered as endogenous, as long as one bears in mind the existence of some distinctive features.⁵

What does the physics establishment think of quantum-mechanical applications in sociology and business? It is easy to suppose physicists mark it down as another instance of scientific misapplication or even outright pseudo-science. In fact, this is far

³Emanuel Derman, *My Life as a Quant: Reflections on Physics and Finance* (Hoboken, NJ: John Wiley & Sons, 2004), 2-3.

⁴Kirill Ilinski, *Physics of Finance: Gauge Modeling in Non-Equilibrium Pricing* (New York: John Wiley & Sons, 2001), 39.

⁵*Ibid.*, 10.

from the truth. “Physics journals publish increasing numbers of papers on financial economics. And increasingly, physicists and mathematicians working on the quantitative side of banking have been joined by PhDs and faculty members from finance departments and business schools.”⁶

This sort of validation has added greater momentum to an already popular practice. For instance, business management gurus are reading popular accounts of quantum physics, which are almost always written from the sensational Copenhagen viewpoint. Margaret Wheatley reads Fritjof Capra, whose popular expositions on New Age implications of physics relies heavily on the CI, and thereafter makes applications in her models for business leadership.⁷ Appealing to standard stereotypes of the so-called Newtonian worldview, she says most business structures are made in the image of Newton’s universe. We practice partite organization, seek to influence primarily by force, and expend great energy in the attempt to predict what we think is a mechanical universe.⁸ Wheatley suggests we ditch this model in favor of ones that reflect insights from the new physics, which, since Capra is her guide, means we must adopt principles described in the CI of quantum physics.

The new physics cogently explains that there is no objective reality out there waiting to reveal its secrets. There are no recipes or formulas, no checklists or expert advice that describe ‘reality.’ If context is as crucial as the science explains, then nothing really transfers; everything is always new and different and unique to each of us.⁹

⁶Derman, *My Life*, 3.

⁷Margaret J. Wheatley, *Leadership and the New Science: Discovering Order in a Chaotic World*, 2nd ed. (San Francisco: Berrett-Koehler, 1999), 3-4.

⁸Ibid., 7. Doug DeCarlo also bemoans the fact that “Newtonian thinking” pervades the business world and creates “absurd project management behavior.” He emphasizes the need to embrace the “quantum mindset,” which emphasizes change, uncertainty, and “right-brained principles.” Heisenberg’s Uncertainty Principle plays a significant role in shaping DeCarlo’s model. Doug DeCarlo, *Extreme Project Management: Using Leadership, Principles, and Tools to Deliver Value in the Face of Volatility* (San Francisco: Jossey-Bass, 2004), 15-19.

⁹Wheatley, *Leadership*, 9.

Wheatley goes on to emphasize the importance of relationship in the quantum world. She cites the standard Copenhagen view that “particles come into form and are observed only as they are in relationship to something else. They do not exist as independent ‘things.’”¹⁰ Wheatley believes this can inform our everyday business and leadership practices in the following way.

As more of us contemplate these strange behaviors at the subatomic level, I believe we are given potent images that can enrich our lives at the macro level. Quantum imagery challenges so many of our basic assumptions, including our understanding of relationships, connectedness, prediction, and control. It may also be true that quantum phenomena apply somewhat to us large-sized objects, literally more than we had thought.¹¹

Here we see a theme that is common among those who explore possible non-physics applications of quantum theory: quantum strangeness may have some direct causal bearing on events in everyday life, and if the quantum world is in truth as astonishing as theorists typically claim it is, surely it is fair to draw from quantum imagery in our efforts to construct worldviews even if the direct causal bearing of quantum mechanics on macroscopic objects is limited. Such constructive efforts are especially important for an era in which traditional, authoritarian metanarratives are rejected in favor of personalized narratives. When the books of religion are set aside in favor of the science journals, those narratives more often than not are shaped significantly by predominate views in science. The Copenhagen emphasis on paradox seems to be a uniquely fit tool for this because the narratives constructed by individual persons often contain tensions or outright contradictions with others of their beliefs or practices. If paradox is instantiated in the real world of physics, the presence of paradox in a worldview might seem excusable. Hence, the CI can serve as a justifying grounds for worldview systems whose components parts are disparate and conflicting.

¹⁰Ibid., 11.

¹¹Ibid., 33.

Feminism and Race

Donna Wilshire believes advances in quantum science have prescribed the overthrow of the objective model of knowledge and called forth an emphasis on feminist themes. Interestingly, she says Bohr and Heisenberg helped show the way by their emphasis on the subjectivity of both the scientist and the quantum system in the measurement process.

The Great Goddess is what Carol Christ and James Hillman are asking for: an archetypal female image that can inform and reform our view of the world. Bohr and Heisenberg, as I have indicated, had to discount formal ‘objectivity’ (the view from ‘out there,’ Apollo’s realm) in order to achieve a coherent view of physics. If this is true of the ‘hardest’ of sciences, then philosophy and the social sciences can also benefit by dethroning Apollo as the exclusive model and symbol for knowledge. The Mother Goddess, better than Apollo, captures our actual situation, which is *in the world* rather than ‘out there’ like Apollo. She, with Her earth-body wisdom, is an Image, Parable, and Metaphor that *incorporates* (‘has in the body’) our ‘what’ and at the same time the ‘means-by-which’ we must proceed to acquire knowledge.¹²

Wilshire’s emphasis on quantum physics being the “hardest” sort of science is quite mistaken, and I will argue this point in chapter 5. For Wilshire, however, quantum science is one of the surest things going, and in the light of its revelations we see new patterns for epistemology generally and science particularly. For instance, she foresees a day when poetry, oral history, as well as literary allusion and emotion, will play recognized roles in the standard practice of science and the discussion of ideas vital to humanity.¹³ Wilshire provides the following example of what this might look like in the practice of science.

There are many already-existing models for the new science and epistemology I propose. One is Barbara McClintock’s work on the genetic structure of corn seeds, research that beautifully exemplifies the way of Myth as the way of Science. Interestingly, Persephone was not just any seed; She was specifically the corn seed. I am reminded of our early foremothers and their belief that divinity (Knowledge) is immanent in nature and how that led them to discover that seeds can be reborn. When doing her revolutionary experiments, McClintock abstained from the traditional sci-

¹²Donna Wilshire, “The Uses of Myth, Image, and the Female Body in Re-visioning Knowledge,” in *Gender/Body/Knowledge: Feminist Reconstructions of Being and Knowing*, ed Alison M. Jaggard and Susan R. Bordo (New Brunswick, NJ: Rutgers University Press, 1989), 110.

¹³Ibid., 105.

entific, legalistic, pharisaical method: that determines objectivity with one's detached mind what the rules of science are and then superimposes them on one's work. Instead McClintock became emotionally involved with her corn seed kernels. She listened and watched patiently, without ego, letting the corn reveal itself to her, 'allowing' what was immanent within the seed kernel to teach her about itself. She imposed no preconceived notions onto the PATTERNS the corn exhibited. Rather, the corn told her what its Nature was; she, having her ears open, heard.¹⁴

Angela Tilby shares Wilshire's belief that quantum science is leading us into a new era for epistemology. She appeals to wave-particle duality to justify the claim that nature is dualistic, by which she apparently means complementary, and hopes this will encourage society to forego the "monistic vision," which includes a monistic metaphysics and an emphasis on the male interpretive standpoint.¹⁵

Barbara Holmes incorporates elements of the CI into her fight for racial equality. Centering her argument especially on Heisenberg's Uncertainty Principle, Holmes makes a case that IQ-testing and other sorts of quantitative evaluations neglect the importance and reality of uncertainty in measurement. Dominant social classes, she says, emphasize the ability to measure intelligence accurately because it eliminates uncertainty and fear, presumably because categorization justifies suppression and control. The suppressed classes, however, relish uncertainty, for it offers them a glimmer of hope.¹⁶

In the quantum world there is a reality, but at the most fundamental levels it can only be described as potential. In our world there is potential in each and every human being; however, patriarchy, racism, and other oppressive systems limit and inhibit the options. We cannot take the measure of another human being with any accuracy. Tests only point to the place where potential might bloom.¹⁷

In a manner similar to Wheatley above, Holmes is apparently not claiming that quantum phenomena are necessarily directly influential in our everyday experience in clearly discernible ways, but rather that if the quantum world is really this way, we can draw images from it to aid our ordering of life experiences. In Holmes's case specifically,

¹⁴Ibid., 104.

¹⁵Angela Tilby, *Soul: God, Self and the New Cosmology* (New York: Doubleday, 1993), 173.

¹⁶Barbara A. Holmes, *Race and the Cosmos: An Invitation to View the World Differently* (Harrisburg, PA: Trinity Press International, 2002), 125-26.

¹⁷Ibid., 127.

the genuine uncertainty of quantum events procures for us an image applicable to the liberation of human potential.

Holmes also makes much of the Copenhagen doctrine of complementarity, the application of which she believes might end the abuses of certitude and intelligence measurement.

[In complementarity theory] we are being encouraged to live with the tension of contradictory and opposing ideas. We are all good/evil, victim/victimizers. If the potential for the full spectrum of emotions and responses remained dynamic, abuse might end. It is the desire for certitude that allows us to veer toward one possibility or another. Once the wave/particle potential collapses during our observations or measurements of one another, we take on a degraded aspect of humanity. For any manifestation of personhood that can be defined by one idea or another is idolatrous. The task before us is to return to a dynamic state and to allow others to do likewise.¹⁸

In this quote, Holmes expresses disdain for certainty, but this may not confront the Christian view on the certainty of objective truth if she only has in mind the tendency to form fixed judgments about human potential. However, she elsewhere makes it clear that she is arguing for a non-hierarchical universe and a plurality of moral values. “The struggle among diverse cultures for primacy reflects a view of the universe that is completely hierarchical. The quantum world refutes this assumption and induces us to accept a space that allows growth and mutuality.”¹⁹ If ours is not a hierarchical universe, what sort of universe is it? Holmes appeals to quantum science and recent cosmology to argue for a form of holism. We are all connected in unexpected ways, she says, and justice seekers ought to awaken to the implications.²⁰ The implications, stemming as they do from Copenhagen doctrines of physical holism and contradiction-embracing complementarity, are clearly in tension with standard Christian views of the laws of logic (which reject real contradictions) and real ontological distinctness between particulars.

¹⁸Ibid., 130-31.

¹⁹Ibid., 123-24.

²⁰Ibid., 3.

Applications in Philosophy

Philosophy of Science

The conflict between the CI and alternative interpretations of quantum theory is often described as a battle in the larger war between realists and anti-realists, and anti-realists regularly cite Bohr's supposedly definitive refutation of EPR as evidence that anti-realism has carried the day.²¹ Bohr himself might have been pleased with this outcome, for he said the scientist's purpose in describing nature "is not to disclose the real essence of the phenomena but only to track down, so far as it is possible, relations between the manifold aspects of our experience."²² Jan Faye, a significant interpreter of Bohr's thought, indicates that realism has no place in Bohr's description of quantum nature.²³ However, a decision between realism and anti-realism in Bohr's thought is not at all simple. His statements on the matter of diverse rather than unified, and some elements of this system seem to imply realism.

Was the Copenhagen interpretation of quantum mechanics antirealist in its thrust? Did Bohr's 'complementary principle' imply that the theoretical entities of the new mechanics do not license any sort of existence claims about the structures of the world? It would seem not, for Bohr argues that the world is much more complex than classical physics supposed. . . . He is not holding that from his interpretation of quantum mechanics nothing can be inferred about the entities of which the world is composed; quite the reverse. He is arguing that what can be inferred is entirely at odds with what the classical view would have led one to expect.²⁴

McMullin's point is well made, and it ought to play a vital role in any assessment of the realism debate in quantum physics. However, the anti-realist tendencies among Copenhagen theorists cannot be ignored. Arthur Fine notes, for instance, that Heisenberg's paper on the Uncertainty Principle included an important disclosure about

²¹Ernan McMullin, a realist, notes this tendency. Ernan McMullin, "A Case for Scientific Realism," in *Scientific Realism*, ed. Jarrett Leplin (Los Angeles: University of California Press, 1984), 12.

²²Niels Bohr, *Atomic Theory and the Description of Nature* (Cambridge: Cambridge University Press, 1934), 18.

²³Jan Faye, *Niels Bohr: His Heritage and Legacy. An Anti-Realist View of Quantum Mechanics*, vol. 6 of *Science and Philosophy*, ed. Nancy J. Nersessian (Boston: Kluwer Academic Publishers, 1991), 217.

²⁴McMullin, "A Case," 12.

his philosophical stance. “In this paper,” said Heisenberg, “an attempt will be made to obtain bases for a quantum-theoretical mechanics based exclusively on relations between quantities observable in principle.”²⁵ Heisenberg follows this introductory comment by rejecting all references to unobservables (such as hidden variables that preserve causality and values independent of observation) and insisting that we ought *not* to try forming a picture of the underlying reality of quantum mechanics.²⁶ Fine goes on to say that quantum theory has predominantly been construed along anti-realist lines since 1927.

This nonrealist position [espoused especially by Heisenberg and inconsistently by Bohr] was consolidated at the time of the famous Solvay conference, in October of 1927, and is firmly in place today. Such quantum nonrealism is part of what every graduate physicist learns and practices. It is the conceptual backdrop to all the brilliant successes in atomic, nuclear, and particle physics over the past fifty years. Physicists have learned to think about their theory in a highly nonrealist way, and doing just that has brought about the most marvelous predictive success in the history of science.²⁷

Christopher Norris notes that the anti-realism circulating among quantum physicists has spread to some significant philosophers, including Hilary Putnam, who gave up on robust realism as a response to interpretive difficulties in quantum theory.²⁸ Specifically, Putnam’s migration was driven by his adoption of elements unique to the orthodox interpretation.

Putnam’s journey has taken him from a realist outlook premised on the existence of an objective (mind-independent) world comprising various objects, attributes, microstructural features, causal dispositions, etc., to an outlook of so-called ‘internal realism’ according to which those various items can only be construed as relative to some favoured descriptive framework or conceptual scheme. This latter approach is likewise characteristic of orthodox (Copenhagen) quantum theory, along with the related empiricist or positivist doctrine which holds that it cannot make sense – at least as regards events at the subatomic level – to posit the existence of an ‘objective’ reality apart from the act of observation or measurement.²⁹

²⁵Heisenberg cited in Arthur Fine, “The Natural Ontological Attitude,” in *Scientific Realism*, ed. Jarrett Leplin (Los Angeles: University of California Press, 1984), 92.

²⁶Ibid.

²⁷Ibid., 93.

²⁸Christopher Norris, *Quantum Theory and the Flight from Realism: Philosophical Responses to Quantum Theory* (New York: Routledge, 2000), 1.

²⁹Ibid., 165.

Norris concludes that the CI indicates a sort of Kantian spin on anti-realism because it reverses the realist priority between ontology and epistemology—that is, ontology has priority over epistemology—by taking epistemological problems in quantum theory to be a reflection of a sort of “noumenal” ontology.³⁰ Plotnitski agrees with the essence of Norris’s assessment, but unlike Norris he accepts the CI and concludes that it implies the end of all realism—“mathematical, physical, or other”—as well as idealism.³¹

Debate also rages about whether or not the CI relies on positivist conceptions. Heisenberg weighs in on the debate and denies that the CI is positivistic, but on the outset it seems the CI is a natural fit with positivism.³² After all, in some renditions the CI refuses to grant the reality of quantum systems that are not under observation, and in all renderings it denies that unobserved quantum systems possess real values. Many interpreters have agreed with this assessment. Peter Forrest, for instance, insists that positivism plays a vital role in the CI, especially insofar as orthodox theorists insist that various statements about quantum systems are neither true nor false.³³ Alastair I. M. Rae thinks it is clear that the CI involves positivism, for it insists that even when measured the quantum system has yielded *contrived* rather than real values, while Max Jammer goes so far as to say the “new conceptual situation in [quantum] physics” cannot be understood apart from the rise of positivism early in the twentieth century.³⁴ Physicist John Bell detects

³⁰Ibid., 195.

³¹Plotnitski rests his case for anti-realism on complementarity. Arkady Plotnitski, *In the Shadow of Hegel: Complementarity, History and the Unconscious* (Gainesville: University Press of Florida, 1993), 35. See also idem, “Complementarity, Idealization, and the Limits of Classical Concepts of Reality,” in *Mathematics, Science, and Postclassical Theory*, ed. Barbara Herrnstein Smith and Arkady Plotnitski (Durham, NC: Duke University Press, 1997), 134, and idem, *Complementarity*, 120.

³²For Heisenberg’s denial that the CI involves positivism, see Werner Heisenberg, *Physics and Philosophy: The Revolution in Modern Science*, vol. 19 of *World Perspectives*, ed. Ruth Nanda Anshen (New York: Harper and Brothers, 1958), 145.

³³Peter Forrest, *Quantum Metaphysics* (Oxford: Basil Blackwell, 1988), 105-06.

³⁴Alastair I. M. Rae, *Quantum Physics: Illusion or Reality?* (Cambridge: Cambridge University Press, 1986): 112; Max Jammer, *The Conceptual Development of Quantum Mechanics*, 2nd ed, vol 12 of *The History of Modern Physics, 1800-1950*, ed. Gerald Holton and Katherine R. Sopka (United States of America: Tomash Publishers, 1989), 184-85. See also Dipankar Home, who likewise concludes that Bohr and Heisenberg displayed a “positivist slant” in their philosophy of science. Dipankar Home, *Conceptual Foundations of Quantum Physics: An Overview from Modern Perspectives* (New York: Plenum Press, 1997), 18.

positivism and instrumentalism among physicists operating in the Copenhagen tradition.

Making a virtue of necessity, and influenced by positivistic and instrumentalist philosophies, many came to hold not only that it is difficult to find a coherent picture but that it is wrong to look for one – if not actually immoral then certainly unprofessional. Going further still, some asserted that atomic and subatomic particles do not *have* any definite properties in advance of observation. There is nothing, that is to say, in the particles approaching the magnet, to distinguish those subsequently deflected up from those subsequently deflected down. Indeed even the particles are not really there.³⁵

It is not hard to guess what impact this sort of philosophy of science has on metaphysics. Richard Kitchener says the CI reduces to the assertion that there is no reality behind quantum phenomena. All we have are mathematical formulas and empirical data, and nothing can be said about quantum “reality.”³⁶ Hence, the only metaphysics possible according to the strictures of the CI is a metaphysics of experience alone, which Kitchener identifies with “process philosophers, pragmatists, phenomenologists, ordinary language philosophers, positivists, phenomenologists, instrumentalists, contextualists, and so on.”³⁷ Importantly, Kitchener argues that ultimately the CI leads to metaphysical pluralism.

Since quantum physics makes no assertions about what is *ultimately real*, it cannot be in conflict with one’s metaphysics. It seems perfectly possible, therefore, for one to accept the results of contemporary science, interpret them as the ‘Copenhagen school’ does, and then hold any metaphysics one wishes. This is precisely why many religious philosophers (for example, Pierre Duhem), existentialists (for example, Martin Heidegger), pragmatists (for example, John Dewey), logical positivists (for example, the early Carnap) and ordinary language philosophers (for example, Gilbert Ryle) have been sympathetic (or would have been sympathetic) to the ‘Copenhagen interpretation,’ which seems to be a version of instrumentalism, phenomenism, or positivism.³⁸

³⁵John S. Bell, “Bertlmann’s Socks and the Nature of Reality,” in *Speakable and Unsayable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 142.

³⁶Richard F. Kitchener, “Introduction: The World View of Contemporary Physics: Does It Need a New Metaphysics?” in *The World View of Contemporary Physics: Does it Need a New Metaphysics?* ed. Richard F. Kitchener (Albany: State University of New York Press, 1988), 6.

³⁷*Ibid.*, 7.

³⁸*Ibid.*, 17-18.

It is important to note that Kitchener's argument depends on a sort of Kantian element in the CI. The "real" is shoved into a noumenal classification, and so in this sense it makes room for "faith" in whatever metaphysical system you choose. Metaphysical pluralism is possible because metaphysical certainty is *impossible*. This conclusion is anathema to Christianity, especially insofar as the tendency is to shove far more than just quantum physics into the unknown noumenal realm.

Norris concludes, contra Kitchener, that the positivistic nature of the CI does not open up manifold metaphysical possibilities so much as it forecloses all metaphysical options.³⁹ In effect, however, Norris and Kitchener are getting at the same thing: metaphysical certainty and/or exclusivism are impossible according to the Copenhagen rendering because "reality" is beyond discovery.

Henry Stapp, one of the most significant interpreters of the Copenhagen metaphysics, explains two reasons why the CI rejects metaphysics.

First, a principle theme in orthodox quantum thinking is precisely the rejection of metaphysics. The orthodox attitude is to renounce the quest for an understanding of physical phenomena in terms of basic realities and to settle for some computational rules that allow scientists to form expectations pertaining to observations obtained under well-defined conditions specified in terms of classical physical ideas. This revision in the announced aim of physics signifies that the clear idea of physical reality provided by classical physics has been snatched away by quantum theory, which provides in its place only computational rules of mysterious origin. Such rules may be sufficient for scientific purposes, but they are not enough for philosophers in search of a unified understanding of all of nature. . . . A second reason for the apparent inadequacy of the quantum physicist's conception of nature as the foundation for a united metaphysics is that the quantum rules effectively replace the mind-matter duality of classical physics by a quantum triality.⁴⁰ [which is] an apparent shift away from, rather than toward, metaphysical unity.

Stapp's second point, that quantum physics cannot provide a foundation for a unified metaphysics, is not troubling from a Christian worldview perspective, for on the Christian view no physical science is capable of such grounding. What *is* troubling is the

³⁹Christopher Norris, "Philosophy of Science as 'History of the Present': Quantum Theory, Anti-Realism, and Paradigm-Change," *New Formations* 49 (2003): 29.

⁴⁰Henry P. Stapp, "Quantum Theory and the Physicist's Conception of Nature: Philosophical Implications of Bell's Theorem," in *The World View of Contemporary Physics: Does It Need a New Metaphysics?* ed. Richard F. Kitchener (Albany: State University of New York Press, 1988), 39.

orthodox view's implication that ontological systems in general are undermined by quantum physics because, in keeping with the positivist/instrumentalism commitments of the CI, all ontological claims are "scientifically unwarranted" because they overstep empirical justification in view of the measurement problem.⁴¹ Again, "reality" has disappeared into a noumenal fog according to the orthodox view.

Quentin Smith helpfully explains how the measurement problem, as expressed by the CI, leads to obfuscation of quantum reality and hence an instrumentalist approach.

The Copenhagen interpretation holds that the macroscopic measuring instrument (including the brain of the observer), is, *in reality*, a quantum-mechanical system. Such an instrument is made up of quantum-mechanical entities and is itself such an entity; but that its quantum-mechanical nature can be bracketed (not described) for purposes of convenience and ease of description, since macroscopic systems appear similar enough to non-quantum entities that their quantum nature can be treated (for instrumentalist purposes) as if it were non-quantum. On this interpretation, the laws of quantum mechanics imply that the macroscopic measuring instrument and the microscopic entity being measured themselves form a new, more complex quantum-mechanical reality . . . such that this macroscopic reality (the measuring instrument M') and the system S being measured constitute the quantum-mechanical reality represented by $[\psi]M + S$ (the state vector of wave function that represents a single quantum-mechanical state, one that can in turn be measured by another measuring instrument M).⁴²

Smith goes on to make an important note about how the Copenhagen interpretation relates to realism and anti-realism in view of the instrumentalism he has just described.

In short, each microscopic or macroscopic subsystem of the universe, on the Copenhagen instrumentalist interpretation, is a measurable quantum-mechanical reality relative to some distinct macroscopic subsystem M' that is regarded instrumentally as a macroscopic instrument that measures a quantum system. 'The universe as a whole' is a meaningless expression on the instrumentalist interpretation (since nothing outside the universe can measure it), and there is no part of the universe that is not a quantum-mechanical reality. What's the catch? The catch is that the instrumentalist, antirealist interpretation of quantum mechanics (even if not of other theories) implies something about the nature of reality.⁴³

⁴¹Ibid.

⁴²Quentin Smith, "Why Cognitive Scientists Cannot Ignore Quantum Mechanics," in *Consciousness: New Philosophical Perspectives*, ed. Quentin Smith and Aleksandar Jokic (Oxford: Clarendon Press, 2003), 423.

⁴³Ibid., 423-24.

Hence, Smith holds that the CI is an admixture of instrumentalism, anti-realism, and a variety of realism. John Jefferson Davis suggests the brand of realism the CI adopts could be called “contextual realism” because, on his reading at least, the CI does not imply that the observer creates the quantum system outright, but rather that the observer creates certain of its attributes. Thus, quantum particles “have a definite meaning, value, and existence only in the context of a specific experiment and set of measurements.”⁴⁴ I find it difficult to understand what Davis means by saying on the one hand that the quantum system is not created by observation, but on the other hand, that it is given definite existence only when observed. This sort of doublespeak is common among Copenhagen theorists and philosophers who are sympathetic to this approach to quantum mechanics.

Bas C. van Fraassen, whose philosophy of science closely reflects key features of the Copenhagen view, takes what he calls an “empiricist view” of quantum physics. He defines the empiricist approach as follows.

To be an empiricist is to withhold belief in anything that goes beyond the actual, observable phenomena, and to recognize no objective modality in nature. . . . It must involve throughout a resolute rejection of the demand for an explanation of the regularities in the observable course of nature, by means of truths concerning a reality beyond what is actual and observable, as a demand which plays no role in the scientific enterprise.⁴⁵

This, too, kills metaphysics. After all, constructive empiricism is incapable of justifying anything more than empirical *adequacy* in explanation.⁴⁶ As metaphysics goes beyond mere empirical adequacy, it extends beyond justification. Norris concludes that van Fraassen’s philosophy of science is, along with that of other Copenhagen theorists, positivistic, verificationist, and eliminative of metaphysics.⁴⁷

⁴⁴John Jefferson Davis, *The Frontiers of Science and Faith: Examining Questions from the Big Bang to the End of the Universe* (Downers Grove, IL: InterVarsity Press, 2002), 62.

⁴⁵Bas Van Fraassen, *The Scientific Image* (Oxford: Clarendon Press, 1980), 202-03.

⁴⁶Ibid., 12.

⁴⁷Norris, *Quantum Theory*, 29-30.

In summary, though commentators wrangle over the specifics, it seems clear that the CI adopts a philosophy of science that incorporates wholly or in part the following positions: positivism, instrumentalism, operationalism. As for the realism/anti-realism debate, it is very difficult to pin an official position to the orthodox view. On the one hand, Copenhagen theorists and their interpreters will sometimes, as with Penrose above, state clearly that quantum reality does not exist apart from scientific measurement.⁴⁸ On the other hand, some maintain that the CI only claims that quantum systems are “real yet indefinite” until observed. In any case, I conclude that either rendering of the CI reduces to essentially the same thing. If a quantum system “really exists” but does so without any definite values until observed, what exactly is it that exists? It is incoherent to say, as do some Copenhagen theorists, that the system exists in an indeterminate state prior to observation, for such a claim reduces essentially to the assertion that the system simply does not meaningfully exist until observed due to the fact that we can say nothing definitive of its state. The system is drawn out from the fog and made real only when measured. This conclusion is forcefully supported by John Wheeler’s contention that “No elementary phenomenon is a phenomenon until it is a registered (observed) phenomenon.”⁴⁹ If the Copenhagen theorist says no real phenomena occur until a scientific observation is made, surely he means to say “nothing is there” before observation. The CI, therefore, is at base a strong version of anti-realism.

Quantum Logic

The quantum paradoxes have led some philosophers to conclude that our conceptions of logic must be modified. Ironically, Niels Bohr was against revising logic. As Hilary Putnam explains, classic logic plays an important role in the CI.

⁴⁸Roger Penrose, *The Emperor’s New Mind: Concerning Computers, Minds, and the Laws of Physics* (Oxford: Oxford University Press, 1989), 226.

⁴⁹John Archibald Wheeler, “Law without Law,” in *Quantum Theory and Measurement*, ed. John Archibald Wheeler and Wojciech Hubert Zurek (Princeton: Princeton University Press, 1983), 184.

Advocates of the Copenhagen interpretation have always insisted upon classical logic. (I have seen a transcript of a discussion between von Neumann and Bohr in which Bohr said, 'But the whole point of the Copenhagen Interpretation was to avoid changing the logic.') This is what makes the Copenhagen interpretation so peculiar; on the one hand, the whole thrust is 'don't talk about unmeasured phenomena'; on the other hand, the Copenhagen interpretation *requires* a distinction between measured values and unmeasured phenomena, because classical logic is retained. This means that the Copenhagen theorist *has* to talk about unmeasured phenomena, if only to say, 'we can't conceive them with our classical minds'.⁵⁰

What Putnam is getting at here is that, on Bohr's view, the classic logic ought to be retained in spite of (or perhaps *because* of) the sense of paradox it incites in quantum theory. Retention of classical logic insures that quantum reality is beyond description, which fits with positivist and anti-realist elements in the CI. Paul Feyerabend notes that some philosophers, Putnam and Hans Reichenbach among them, dislike this approach because it makes statements about unobserved quantum phenomena meaningless.⁵¹ Hence, it seems an interesting twist that the acceptance of Copenhagen's completeness claim and its emphasis on various quantum paradoxes has encouraged some realists to explore the possibility of revising standard logic.

From the very beginning quantum logic was aimed at restoring realism in quantum physics against Bohr's views. Rather than sticking to 'phenomena' or 'observation' as Bohr did, quantum logic enabled one to recover the possibility of speaking of 'physical qualities,' or of properties of systems, at the cost of changing the algebra (namely, the combination by conjunction and disjunction) of these properties.⁵²

Robert Audi explains the revisionist agenda in similar terms.

The basic argument is that by far the best way of resolving these apparent contradictions [instantiated in the CI of quantum physics] is to admit that classical logic does not apply to these phenomena and to 'read off' the allegedly correct logic from (the mathematical apparatus of) the quantum mechanical theory that correctly predicts the phenomena in question.⁵³

⁵⁰Hilary Putnam, *Realism and Reason*, vol. 3 of *Philosophical Papers* (Cambridge: Cambridge University Press, 1983), 268.

⁵¹Paul Feyerabend, "Reichenbach's Interpretation of Quantum-Mechanics," *Philosophical Studies* 9 (1958): 54-55.

⁵²Michel Bitbol, "A Cure for Metaphysical Illusions: Kant, Quantum Mechanics, and Madhyamaka," in *Buddhism & Science: Breaking New Ground*, ed. B. Alan Wallace (New York: Columbia University Press, 2003), 344.

⁵³Robert Audi, *The Interpretation of Quantum Mechanics* (Chicago: University of Chicago Press, 1973), 100.

An important underlying assumption in revisionist programs, then, is that logic is empirical. Hilary Putnam, for instance, has said that logic is as empirical as geometry.⁵⁴ When one turns to examine the empirical returns of quantum physics, read along Copenhagen lines, one discovers evidence for a 3-valued logic by which propositions may be of true, false, or “middle” value.⁵⁵ Apparently because of the pervasive reach of quantum reality—*everything* is made of quantum particles—this quantum logic is regarded as the true logic, the standard with which all physical law must be compatible.⁵⁶

Reichenbach also adopts a 3-valued logic in response to quantum physics. He too is pushed in this direction because the Copenhagen claim that quantum theory is presently complete is so generally accepted that there seems no way to avoid the quantum paradoxes except to modify logic itself. “The nature of quantum mechanical occurrences is of such a kind that statements of causal anomalies can be eliminated from the domain of true statements only if a three-valued logic is used; this is the form in which we must express the causal structure of the microcosm.”⁵⁷

Susan Haack, in her important essay on revisionist logic, makes the following assessment of Reichenbach’s (and Putnam’s) motivations for the middle-logic proposal. “Reichenbach’s argument has this general structure: if classical logic is used, quantum mechanics yields some unacceptable consequences, the ‘causal anomalies’. But if 3-valued logic is used, these anomalies can be avoided, and this is, furthermore, the least cumbersome way of avoiding them.”⁵⁸

⁵⁴Hilary Putnam, “How to Think Quantum-Logically,” *Synthese* 29 (1974): 55.

⁵⁵See Hilary Putnam, “Three-Valued Logic,” *Philosophical Studies* 8 (1957): 73-80.

⁵⁶Putnam, “How to Think,” 61.

⁵⁷Hans Reichenbach, *Philosophic Foundations of Quantum Mechanics* (Berkeley: University of California Press, 1944), 43. Wave-particle duality is one of the chief paradoxes driving Reichenbach’s revisionist program. *Ibid.*, 24-32.

⁵⁸Susan Haack, *Deviant Logic, Fuzzy Logic: Beyond the Formalism*, 2nd ed. (Chicago: University of Chicago Press, 1996), 150.

Here again, classical logic seems inadequate only if Copenhagen has really gotten it right that quantum theory is complete, such that no hidden variables exist and that acausality, indeterminism and other anomalies are genuine aspects of quantum reality. Interpretations of quantum theory that deny the completeness of our current understanding supply no reason to revise standard logic, for hope remains that future advances will bring quantum theory to greater completion and thereby explain away its current anomalous features.

Haack notes that revisionists differ over whether or not the reformation of logic ought to be local or universal. Some hold that local revision (local = quantum realm only) is all that is necessary, for classical logic is sufficient for describing macrosystems, but Haack suspects the revisionist program really includes the belief that classical logic is never completely valid even for macrosystems.⁵⁹ Hence, on her reading, the revisionist program entails that 3-valued logic is the only true logic, but that 2-valued logic is serviceable because it leads merely to *negligible* errors when applied to classical systems. This is also essentially the conclusion Peter Mittelstaedt reaches in his treatment of quantum logic.⁶⁰

Assessing the case for quantum logic. The call for revisionist logic has incited many strong responses, but none have been more colorful than that given by Karl Popper.

We should (in the empirical sciences) use the full or classical or two-valued logic. If we do not use it but retreat into the use of some weaker logic – say, the intuitionist logic, or some three-valued logic (as Reichenbach suggested in connection with quantum theory) – then, I assert, we are not critical enough; it is a sign that some-

⁵⁹Ibid., 166.

⁶⁰“The ‘true’ logic is given by the calculus of full quantum logic, whereas ordinary effective logic and classical propositional logic are formal systems, the validity of which is restricted to the special case of unrestrictedly available (commensurable) propositions. In particular, propositions about physical systems have this property to the extent that the system in question can be considered a classical one. Consequently, from this point of view classical propositional logic turns out to be an idealisation, which had only approximate validity and, thus, no fundamental meaning.” Peter Mittelstaedt, *Quantum Logic* (Boston: D. Reidel Publishing Company, 1978), 140.

thing is rotten in the state of Denmark (which in this case is the quantum theory in its Copenhagen interpretation).⁶¹

Popper saw clearly that if the CI were not the dominant rendering of quantum meaning, no one could cite quantum mechanics as evidence for alternative logics. Peter Gibbins also comes out against revisionist programs, even those that argue for strictly local reform, for all such programs fail adequately to account for “the logical ‘cut’ between the micro- and macroworlds.”⁶² In other words, none of the revisionist accounts are able to give criteria for judging where and how one must switch logics. To say that the switch occurs when one’s inquiry involves the quantum realm is not sufficient because all objects, no matter how large or small, are composed of quantum particles. If the study of a single quantum particle calls for quantum logic, how many particles must be added to the system before we switch to classical logic? No revisionist has offered a feasible solution to this problem.

Another point of critique centers on the revisionist presumption that logic is empirical. Gibbins notes that Putnam’s call for revision hinged on a response to the empirical data.⁶³ This approach to logic is problematic on two fronts. First, one must have an a priori commitment to logic or else empirical judgments are impossible. If logic is a precondition for the ability to judge sense data, logic itself cannot be empirical. Second, the very act of revision undermines the argument for revision. Norris describes this problem very clearly.

Putnam’s revisionist case with regard to classic logic . . . leaves him with no means of explaining why the anomalies of orthodox QM should be thought of as *logically* entailing any such revision. For if one lets go of those criteria then it is far from clear why any given item of empirical evidence (such as the wave-particle dualism or the limits of precise measurement on conjugate quantum variables) should carry

⁶¹Karl Popper, “A Realist View of Logic, Physics, and History,” in *Physics, Logic, and History*, ed. Wolfgang Yourgrau and Allen D. Breck (New York: Plenum Press, 1970), 18.

⁶²Peter Gibbins, *Particles and Paradoxes: The Limits of Quantum Logic* (Cambridge: Cambridge University Press, 1987), 143.

⁶³*Ibid.*, 144.

any *logical* implications whatsoever, least of all far-reaching implications with regard to the limits of classical logic.⁶⁴

The revisionist program has also been criticized for the fact that it results in a loss of simplicity and familiarity. Willard Van Orman Quine once held that the switch to 3-valued logic was no more momentous than other significant transitions in the history of science, such as those that witnessed scientists give up Ptolemy for Kepler, or Newton for Einstein.⁶⁵ Quine later tempered this stance by noting that “complicating logic to cut fat from quantum physics” is probably not worth losing simplicity and familiarity.⁶⁶

In summary, it is the dominance of the CI that incites the revolution in logic. Fortunately, the shortcomings of revisionist programs are well known and it is relatively uncommon to find anyone defending 3-way logic on the basis of quantum physics.⁶⁷ However, the rhetoric coming from Copenhagen quarters regarding the “truth-problem” indicates that the fight for truth is far from over, even if 3-way logics have failed to gain acceptance.

Truth and Reason

Danah Zohar, the principle author of *The Quantum Society*, studied under the chief opponent of the CI, David Bohm, and yet maintains several views that are in line with Bohr’s interpretation. In particular, she adopts the complementarity doctrine and argues that it signals the *invalidity* of either/or thinking. As she says, “We have to learn to get beyond apparent contradictions.”⁶⁸ This is one mark of the quantum society she hopes quantum science will usher in. Roland Omnès, whom we earlier cited as saying the CI

⁶⁴Norris, *Quantum Theory*, 218.

⁶⁵Willard Van Orman Quine, *From a Logical Point of View: 9 Logico-Philosophical Essays* (New York: Harper and Rowe, 1961), 43.

⁶⁶Willard Van Orman Quine, *Philosophy of Logic* (Englewood Cliffs, NJ: Prentice-Hall, 1970), 86.

⁶⁷As Quine notes, “Most theoreticians of quantum mechanics have passed over these reforms [of logic].” *Ibid.*

⁶⁸Danah Zohar and Ian Marshall, *The Quantum Society: Mind, Physics, and a New Social Vision* (New York: Quill, 1994), 41-42.

has no serious competitors, says quantum mechanics has caused the collapse of former principles such as intelligibility, causality, discernability, and cognizability of the world.⁶⁹ So, reason as we have known it has collapsed under the weight of quantum discoveries. In its place we must adopt “new principles,” the logic of which is based in matter (quantum entities) rather than mind, if we are to forge a new rationality.⁷⁰

It is tempting to suppose that Zohar and Omnès are extending the CI beyond the intentions of its founders, but this is mistaken. Max Born, one of Bohr’s most significant collaborators in the founding of the CI, said, “ideas such as absolute certainty, absolute precision, final truth, etc. are phantoms which should be excluded from science.”⁷¹ That he believes the loss of absolute truth should extend beyond the claims of strict science is made obvious by an elaboration he makes in almost the next breath. “This loosening of the rules of thinking seems to me the greatest blessing which modern science has given us. For the belief that there is only one truth and that oneself is in possession of it, seems to me the deepest root of all that is evil in the world.”⁷²

Here, Born holds that science (read: *quantum* science) has gifted the world with a mandate for greater epistemic humility. He calls for more than humility, actually, since relativism is the inevitable result if “the belief that there is only one truth” on a given matter is ruled out completely.

Bohr held a position similar to Born’s, namely, the belief that the opposite of a profound truth is generally another profound truth.⁷³ It is not difficult to see that Bohr’s quantum interpretation supports this sort of relativism, for as Trevor Pinch notes, Bohr’s

⁶⁹Roland Omnès, *Quantum Philosophy: Understanding and Interpreting Contemporary Science*, trans. Arturo Sangalli (Princeton: Princeton University Press, 1999), 238.

⁷⁰Ibid.

⁷¹Max Born, *Physics in My Generation*, 2nd ed. (New York: Springer-Verlag, 1969), 142.

⁷²Ibid., 143.

⁷³Ken Wilber, *The Spectrum of Consciousness* (Wheaton, IL: Theosophical Publishing House, 1989), 39.

complementarity doctrine is fundamentally a violation of the principle of non-contradiction.⁷⁴ Gregorio Morales agrees that complementarity violates the law of non-contradiction, but adds that the Uncertainty Principle, quantum non-separability, and quantum acausality—all staples of the CI—also weigh in against non-contradiction.⁷⁵

Not surprisingly, several commentators have taken the CI to justify Eastern mystical outlooks on the world, a point that I will cover in greater depth in the next chapter. D. S. Kothari celebrates complementarity for the fact that it calls us “to move on to a deeper layer or a new plane of reality corresponding to the simultaneous existence of both *A* and its negation.”⁷⁶ Gary Zukav says the CI does away with the correspondence theory of truth, thus banishing absolute truth.⁷⁷

Zohar highlights analogies between quantum mechanics and the search for truth in religion, and concludes that all truths are only “partial expressions of a ‘higher’ or a ‘deeper,’ and ultimately inexpressible, truth.”⁷⁸ Making public this *truth about truth* might solve many of the world’s problems, says Zohar. “It is because we have remained under the spell of monotheism, or the belief in one, simple, singular truth, that the history of the West is a history of intolerance and bloodshed, a history of crusades and holy wars, of inquisitions, of guillotines, pogrom and holocaust.”⁷⁹

⁷⁴Trevor J. Pinch, “What Does a Proof Do If It Does Not Prove? A Study of the Social Conditions and Metaphysical Divisions Leading to David Bohm and John von Neumann Failing to Communicate in Quantum Physics,” in *The Social Production of Scientific Knowledge*, ed. Everett Mendelsohn, Peter Weingart, and Richard Whitley (Boston: D. Reidel Publishing, 1977), 203.

⁷⁵Gregorio Morales, “Overcoming the Limit Syndrome,” in *The World of Quantum Culture*, ed. Manuel J. Caro and John W. Murphy (Westport, CT: Praeger, 2002), 4-6.

⁷⁶D. S. Kothari, “The Complementarity Principle and Eastern Philosophy,” in *Niels Bohr: A Centenary Volume*, ed. A. P. French and P. J. Kennedy (Cambridge, MA: Harvard University Press, 1985), 331.

⁷⁷Gary Zukav, *The Dancing Wu Li Masters: An Overview of the New Physics* (New York: William Morrow and Company, 1979), 63.

⁷⁸Zohar, *Quantum Society*, 137.

⁷⁹*Ibid.*, 141. Zohar elsewhere indicates that religion is out and science and psychology are in as the new forces which must shape belief. “It is no longer possible to believe in *both* the discoveries of modern science and in the traditional dictates of the Church, and, for increasing numbers of people today, science and psychology have taken the place of traditional religion.” Danah Zohar, *The Quantum Self: Human Nature and Consciousness Defined by the New Physics* (New York: Quill, 1990), 218.

Zohar avoids absolute relativism by distancing herself from those in the Copenhagen tradition who espouse unmitigated observer-created reality. She takes the more moderate Copenhagen line and holds that the act of observation evokes concrete form out from the many possibilities that inhere unmeasured quantum systems.⁸⁰ But as I stated above, it is difficult to see how this preserves observer-independent realism for quantum systems.

Epistemology and Postmodernism

The Copenhagen interpretation of quantum physics lends itself to all sorts of reformist programs for truth, logic, and reason because fundamentally it is an anti-epistemological stance.⁸¹ Menas Kafatos and Robert Nadeau explain that this is because we are united to a universe from which we are nevertheless existentially isolated due to the fact that the physical fundamentals of our being, quantum entities, cannot be known by us.⁸² The system of the world is rigged against human understanding at its most fundamental level.

The CI engenders the sort of epistemological problems encountered in postmodernist constructs, and in fact commentators take developments in quantum mechanics to be a justification for postmodernist views.⁸³ Beller notes that Heidegger cites Heisenberg throughout his works, and that Heidegger in turn influences Derrida.⁸⁴ Plotnitski and

⁸⁰Zohar, *Quantum Self*, 48.

⁸¹Beller, *Quantum Dialogue*, 101. Plotnitski, *Complementarity*, 72.

⁸²Menas Kafatos and Robert Nadeau, *The Conscious Universe: Part and Whole in Modern Physical Theory* (New York: Springer-Verlag, 1990), 117.

⁸³Elke Rechberger, "The Impact of Einsteinian Relativity and Quantum Physics Theories on Conceptualizations of the Self in Psychology" (Ph.D. diss., Fuller Theological Seminary, 1998), 82.

⁸⁴"The problematics of quantum mechanics quite possibly affected Heidegger's conceptions of the lost trace of Being, which play a major role for Derrida, particularly in 'Différance' and 'Ousia and Gramme.' *Being and Time* dates around 1927. *Time and Being* (1962) opens with the invocation of Heisenberg (along with Paul Klee and Georg Trakl), albeit in the Heideggerian terms of the search for a cosmic formula, and references to Heisenberg are found throughout Heidegger's writings. Quantum physics was an important point of reference for Heidegger, particularly in *What is a Thing?*, *What is Called Thinking?*, and 'The Question Concerning Technology' and related essays." Beller, *Quantum Dialogue*, 94-95.

Norris believe that Derrida, the doyen of postmodernist thought, was most likely influenced by quantum physics.⁸⁵ Indeed, postmodern hermeneutic theorists generally have answered the call to make the world in the image of quantum ontology.

Among hermeneutic theorists especially there is a belief that quantum mechanics spells the end of that old ‘metaphysical’ conception of scientific method that strove to draw a firm categorical line between subject and object, mind and world, or epistemology and ontology. We may recall, in this context, that Heidegger dedicated one of his works to Heisenberg; also that he wrote admiringly of Heisenberg and Bohr on account of their willingness to ‘hold out in the questionable’, that is, their acceptance of uncertainty and their courage in venturing beyond the inherited dualisms of Western technometaphysics.⁸⁶

Jean-François Lyotard cites developments in quantum physics, as defined by the CI, as grounding for postmodernist themes in epistemology. He speaks of “postmodern science,” which redefines *knowledge* and produces the unknown rather than the known.⁸⁷ In quantum physics specifically, “the relation between the scientist’s statement and ‘what “nature” says’ seems to be organized as a game without perfect information.” Lyotard elaborates on this point several lines later.

On the level of microphysics, ‘better’ information—in other words, information with a higher performance capability—cannot be obtained. The problem is not to learn what the opponent (‘nature’) is, but to identify the game it plays. Einstein balked at the idea that ‘God plays with dice.’ Yet dice is precisely a game for which this kind of ‘sufficient’ statistical regularities can be established⁸⁸

Employing quantum physics in this manner, namely, as a justification of postmodernist themes, seems to comport with elements of what Bohr and other Copenhagen theorists have said about truth, language, epistemology, and the complementarity of opposites. Bohr himself took “the ambiguity of language” as the starting point for philosophy and science, and displayed many affinities for Wittgenstein’s thought.⁸⁹

⁸⁵Christopher Norris, *Against Relativism: Philosophy of Science, Deconstruction, and Critical Theory* (Oxford: Blackwell, 1997), 114. Plotnitski, “Complementarity,” 145.

⁸⁶Norris, *Quantum Theory*, 195-96.

⁸⁷Jean-François Lyotard, *The Postmodern Condition: A Report on Knowledge*, trans. Geoff Bennington and Brian Massumi (Minneapolis: University of Minnesota Press, 1984), 60.

⁸⁸*Ibid.*, 57.

⁸⁹F. Borg, “The Breakdown of the Common Sense,” in *Symposium on the Foundations of*

Emphasis on the insufficiencies of language and epistemology naturally leads to all manner of relativisms and pluralisms. Sociologist Graciela Elizabeth Bergallo thinks quantum science (according to the CI) opens the way to a new, pluralistic conception of anthropology.

A different approach to anthropology, one based on the validation of alternative knowledge bases and the discoveries of quantum physics—as opposed to positive science—would be better able to provide a more culturally sensitive understanding of these religions’ [i.e., shamanism’s and any other spiritualism’s] phenomena, and, at the same time, illustrate that the old views held by anthropologists are erroneous. . . . The ambiguity of the universe at the quantum level demonstrates that reality is the result of choices made by humans and, thus, can be modified by further action. Simply put, according to quantum physics, reality *does not exist* in itself but *is made*.⁹⁰

This is an important revelation to the Western mind, adds Bergallo, for our colonialist tendencies have undermined or destroyed the ability of many non-Westerners to “enter different layers or reality through visions or dreams, or view reality as consisting of overlapping and dynamic fields, as proposed by quantum theorists.”⁹¹

Bergallo’s “quantum anthropology” is part of a larger “quantum aesthetics” project, which is said to be grounded in hard science (read: quantum mechanics) rather than immaterial ideas. This grounding gives quantum aesthetics the same legitimacy as positive science.

Furthermore, this project should surpass positive science for it breaks away from the untenable dualism and realism that has plagued science since the Renaissance. Indeed, the separation between the physical and immaterial world is shown to be false by quantum aesthetics: intuition and matter are integrated in an undifferentiated whole.⁹²

Modern Physics 1987: The Copenhagen Interpretation 60 Years After the Como Lecture, ed. Pekka Lahti and Peter Mittelstaedt (Singapore, World Scientific, 1987), 300-01.

⁹⁰Graciela Elizabeth Bergallo, “The Interpretative Foundations of Culture: Quantum Aesthetics and Anthropology,” in *The World of Quantum Culture*, ed. Manuel J. Caro and John W. Murphy (Westport, CT: Praeger, 2002), 146.

⁹¹*Ibid.*, 147.

⁹²Manuel J. Caro and John W. Murphy, “Preface,” in *The World of Quantum Culture*, ed. Manuel J. Caro and John W. Murphy (Westport, CT: Praeger Publishers, 2002), ix.

The union of matter and intuition has important ramifications for Western conceptions of religion and philosophy.

Although consistent with quantum physics, this mixture violates the basic premise of Western religious and intellectual traditions. Throughout history, spirit had to be pristine and a reliable source of inspiration, honor, and truth. In the hands of quantum writers, however, spirit is worldly and thus themes that were formerly idealized now have social and cultural limitations.⁹³

While “spirit” is limited, the scope of quantum physics, and hence quantum culture, is not. Everything is shaped by the new paradigm inaugurated by quantum physics, and for this reason a new culture must emerge.⁹⁴ The end result, according to quantum aesthetics, is a culture of free, open interpretation in which limitation is seen as a form of violence.⁹⁵

Applications in Science

Human Consciousness

Since the orthodox interpretation of quantum mechanics places such great emphasis on the role of human consciousness in quantum measurement, Quentin Smith believes it is inevitable that the effects trade both ways, such that theorists ought to explore ways in which quantum nature defines the nature of consciousness.⁹⁶ In fact, until recent times theorists have been slow to do this, which negligence Smith finds “fundamentally disturbing.”⁹⁷ But this lack is presently being shored up by a host of physicists and cognition-scientists who have taken on the task of outlining the possibilities for quantum-based consciousness.

⁹³Manuel J. Caro and John W. Murphy, “Quantum Aesthetics and the Polity,” in *The World of Quantum Culture*, ed. Manuel J. Caro and John W. Murphy (Westport, CT: Praeger, 2002), 172.

⁹⁴Morales, “Overcoming,” 9.

⁹⁵Ibid., 28.

⁹⁶Smith, “Why Cognitive Scientists Cannot Ignore Quantum Mechanics,” 413.

⁹⁷Ibid., 409.

The first step in any proposal for quantum-based human consciousness is a demonstration of how quantum phenomena might be amplified so as to affect brain mechanisms. Typically, this task is approached in the following manner.

Nerve cells in the human brain are sufficiently sensitive to register the absorption of a single photon (mirroring the passage of an individual electron from one energy state within the atom to another)—and thus sensitive enough to be influenced by the whole panoply of odd quantum-level behavior, including indeterminism and nonlocal effects.⁹⁸

Expanding on the claim that quantum indeterminism comes into play in the operations of neurons, Zohar says experiments that involve random variation of chemical concentrations at synapses prove that “even very slight, quantum-level variations affect the firing potential” of the neurons.⁹⁹ Henry Stapp, whose contributions to research on quantum-based consciousness are numerous and impressive, explains that while Newtonian conceptions of physics cannot deliver a naturalistic explanation for human consciousness, quantum physics as defined by Bohr, Heisenberg, and other Copenhagen theorists can. This is because the heart of the CI is the claim that, in the measurement procedure for quantum systems, human consciousness “is tied tightly to the causally efficacious collapse process.”¹⁰⁰ Smith agrees that, on the CI of quantum mechanics, consciousness causes the wave-function to collapse and that, furthermore, “the emergent, psychological property of *being a conscious state* is an actualization of a potential conscious state that exists in a quantum mechanical configuration space.”¹⁰¹ Human con-

⁹⁸Zohar, *Quantum Self*, 79. Friedrich Beck offers a similar description. “Nerve impulses are stochastic processes that are always present in the living brain. Recent investigations suggest that the neural net stays close to instability, and in this way can be switched between different states by minute action. To control such a system, a stable regulator has to be present that generates a coherent pattern in the active cortical unit. We argue here that the decisive unit in this regulator is a quantum trigger that determines the onset of synaptic exocytosis upon an incoming nerve impulse.” Friedrich Beck, “Synaptic Transmission, Quantum-State Selection, and Consciousness,” in *Toward a Science of Consciousness II: The Second Tucson Discussions and Debates*, ed. Stuart R. Hameroff, Alfred W. Kasniak, and Alwyn C. Scott (Cambridge, MA: MIT Press, 1998), 619.

⁹⁹Zohar, *Quantum Self*, 79.

¹⁰⁰Henry Stapp, “The Evolution of Consciousness,” in *Toward a Science of Consciousness II: The Second Tucson Discussions and Debates*, ed. Stuart R. Hameroff, Alfred W. Kasniak, and Alwyn C. Scott (Cambridge, MA: MIT Press, 1998), 606.

¹⁰¹Smith, “Why Cognitive Scientists Cannot Ignore Quantum Mechanics,” 416. Barry Loewer

consciousness is therefore a quantum phenomenon. Barry Loewer sums up the situation nicely.

Stapp, Penrose, and Smith, for example, claim that while classical mechanics is incapable of accounting for consciousness, quantum mechanics succeeds in providing explanations of how experience, unity of mind, free choice, and other features of mind emerge from physical states. Quantum mechanics-consciousness enthusiasts see a mutual need: quantum mechanics needs consciousness for its formulation—consciousness needs quantum mechanics as its physics. Thus mutual necessity makes for *strange* bedfellows.¹⁰²

The strangeness does not stop here, however, for the involvement of quantum factors in human consciousness means we must be prepared to explore the implications quantum logic has for our epistemological practices. One possibility is that “If-then” reasoning, a staple of classical logic, is not universally valid.¹⁰³ Here we have another call for revision of standard logic.

Assessment of quantum-mechanical consciousness. Not everyone who explores the possible interface between quantum mechanics and human consciousness comes away believing quantum-based consciousness is scientifically feasible. David Chalmers says quantum considerations might help us characterize the link between experience and physical properties of world and brain, but quantum theories postulating a quantum physical *basis* for consciousness cannot escape the fact that “experience must be taken as something over and above the physical properties of the world.”¹⁰⁴

Stuart Hameroff and Alwyn Scott have debated whether or not a quantum-

makes the same claim. “One [reason consciousness involves quantum physics] is that according to the standard way of thinking about quantum theory—known as the Copenhagen Interpretation—measurement and observation play a central role in physical reality in ways that are utterly different from classical mechanics. The theory’s founding fathers said and current orthodoxy concurs that quantum mechanics requires for its *very formulation* reference to the measurement process . . . [and] it is often said that a measurement is not completed until it is registered in the mind of a conscious observer.” Barry Loewer, “Consciousness and Quantum Theory: Strange Bedfellows,” in *Consciousness: New Philosophical Perspectives*, ed. Quentin Smith and Aleksandar Jokic (Oxford: Clarendon Press, 2003), 507-08.

¹⁰²Loewer, “Consciousness and Quantum Theory,” 508.

¹⁰³Beck, “Synaptic Transmission,” 620.

¹⁰⁴David J. Chalmers, *The Conscious Mind: In Search of a Fundamental Theory* (Oxford: Oxford University Press, 1996), 333.

mechanical basis for consciousness is possible. Scott, a decided skeptic of quantum consciousness, notes that the firing of nerve impulses is “a completely classical phenomenon,” a claim that quantum-consciousness advocate Hameroff concedes as true.¹⁰⁵ Hameroff then shuts the door on Zohar’s appeal to random minute variations of neurotransmitter concentration at nerve junctions as a means of explaining quantum consciousness by stating that nerve impulses cannot account for consciousness.¹⁰⁶

Scott then claims that quantum physics, complicated though it may be, is unable to account for the unparalleled complexity of the human brain.

The immensely intricate nonlinear structure of the brain’s dynamics is a much richer source of mystery than quantum theory will ever be. In my opinion, physicists who turn to quantum theory for explanations of such intricate phenomena are looking in the wrong direction. Quantum theory tells us how atoms interact, but little about protein dynamics and nothing about the electrophysiology of the brain. . . . If physicists are truly interested in contributing to our understanding of phenomena related to consciousness, they should acquaint themselves with the relevant neurological facts, which are far more intricate than can be expressed in a quantum formulation.¹⁰⁷

In conclusion, the argument that human consciousness is made possible by or greatly influenced by quantum mechanical operations is highly dubious, and seems generally to rest on the Copenhagen doctrines of indeterminacy and observer-created reality.

Scientific Cosmology

That the heavens are finite in spatial measure has not always been apparent even to those who believe in a generally biblical conception of God and world. Some, such as Immanuel Kant, have reasoned that the expanse must necessarily be infinite, for anything less would fail to reflect the creative power of infinite God. Early advancements in telescopy seemed only to confirm such a cosmology, for the stars nearby our planet

¹⁰⁵Stuart R. Hameroff and Alwyn C. Scott, “A Sonoran Afternoon,” in *Toward a Science of Consciousness II: The Second Tucson Discussions and Debates*, ed. Stuart R. Hameroff, Alfred W. Kasniak, and Alwyn C. Scott (Cambridge, MA: MIT Press, 1998), 637.

¹⁰⁶Ibid.

¹⁰⁷Ibid., 640.

proved to be only the barest fringe of a blanket that appeared to stretch into infinity. By the close of the nineteenth century most cosmologists believed that the universe was infinite in scope and eternal in age. Naturally, this lent itself to naturalistic conceptions of the universe, for it is not at all clear that an eternal, infinite universe has any need for a Creator-God.

Then came a shift—a red shift—inadvertently seen in the night sky of Arizona by an American astronomer. Vesto Melvin Slipher forever changed the course of cosmology when he noted that nearby galaxies appeared at a lower end of the electromagnetic spectrum than the dominant models of his day predicted.¹⁰⁸ Cosmologist Edwin Hubble correctly interpreted this phenomenon as an aspect of what is known as the Doppler Effect. There was only one conclusion to be reached: the nearby galaxies are receding from our viewpoint. Yet cosmologists were reluctant to concede the obvious, for much scientific and philosophic capital had been invested in cosmological models that would not admit anything such as receding galaxies. So astrophysicists and cosmologists held out, hoping for decades that new discoveries would squelch the clamor over Slipher’s unwelcome discovery. But the discomfiting complaints in the observatories and universities were destined to become a deafening roar, for one after another the findings piled up, all of them leading to one inevitable conclusion: the universe began to exist from a common, finite “point” in the finite past in an event commonly called the Big Bang.

Today, the evidence that cosmological origins must be explained by some version of the Big Bang model is overwhelming. As Brian Greene notes, the evidence for Big Bang cosmology is “impressive almost to the point of hubris.”¹⁰⁹ In this light, one might expect that theistic conclusions regarding ultimate origins are inevitable, especially

¹⁰⁸Michael A. Corey, *God and the New Cosmology: The Anthropic Design Argument* (Lanham, MD: Roman and Littlefield Publishers, 1993), 29.

¹⁰⁹Brian Greene, *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory* (New York: Vintage Books, 1999), 349.

among physicists who have seen and understood the evidence. In fact, a case for an atheistic universe remains a live option in the opinion of some physicists and philosophers, and as the following survey will conclude, the CI of quantum physics is at the heart of the appeal.

Quantum physics comes into play from the very outset in contemporary models for the universe's origin. Extrapolating backwards to the very earliest moments of the universe's expansion, we find that there was a time when quantum particles were crowded together closely enough that quantum effects must have been significant.¹¹⁰ Elements of the CI may come into play in several ways. Two possibilities, discussed in detail by Kafatos and Nadeau, involve complementarity and the observation problem (read along Copenhagen lines) and the limitation these may have on cosmological knowledge. Complementarity, they say, comes into consideration in the following way. As we peer into deep space through our telescopes, photons, "our principle source of knowledge about phenomena in the early universe, become fewer and fewer in number."¹¹¹ This saddles us with problems when we attempt to observe galaxies that lie in the outer reaches of our instrument's capacities. In the nature of the case, a choice must be made between accurately determining position and distance of a galaxy simultaneously.

This means that we are eventually observing photons on our telescopes which are so few in number that wave-particle duality, and thus quantum uncertainty, could have substantive consequences in making acts of observation. In these situations the 'choice' of whether to record the particle or wave aspect could have appreciable consequences. This, we believe, may turn out to be the cause. The photographic evidence produced by these observations involves the particle aspect of light quanta, and observations based on special analysis involve the wave aspect of these quanta. If we are observing only a few photons from very distant sources at the edge of the observable universe, it would seem that the resulting indeterminacy would be imposing some limits on the process of observation. Our view is that *complementarity will have to be invoked in our efforts to understand the early life of the universe based on observations involving few light quanta due to the irremedial ambiguities introduced by the quantum of action.*¹¹²

¹¹⁰Steven Weinberg, *Dreams of a Final Theory* (New York: Pantheon Books, 1992), 85.

¹¹¹Kafatos and Nadeau, *The Conscious Universe*, 161.

¹¹²*Ibid.*

Following this up a bit, Kafatos and Nadeau add that depending on what observational choices the experimenter makes when viewing a small sample of photons through his telescope, logically different views of the universe may emerge.¹¹³ The next step for Kafatos and Nadeau is essentially inevitable given their appeal to complementarity.

The apparent fact that observation in such situations suggests that we must invoke wave-particle duality becomes particularly intriguing when we consider that observational limits appear to be a consequence of adopting ‘single’ and ‘specific’ theoretical models of the universe. . . . The radical suggestion here, which will doubtless disturb many cosmologists, is that these horizons of knowledge are testifying to the fact that the observed system is a quantum system. If this is the case, then it is conceivable that single and specific models create ambiguities which cannot be resolved within the context of those models because we have failed to consider the prospect that logically disparate models could be complementary . . . [which means that] disparate cosmological models . . . taken together, define the entire situation.¹¹⁴

Now we are back to Bohr’s take on opposites: the opposite of a profound truth is another profound truth, or as his coat of arms says, “Opposites are compliments.”

Kafatos and Nadeau go on to explain that the Big Bang singularity was the first instantiation of complementarity. The opposites marked by “the nothingness of the vacuum state and the somethingness of the quantum of action” are complementary, and arose from a “fluctuation in the vacuum state caused by the quantum of action that resulted in creation.”¹¹⁵ Complementarity is permanently infolded into the structure of the universe from the singularity forward, and thus inheres all of creation to this very day. In the end, Kafatos and Nadeau embrace a phenomenal-noumenal distinction and conclude that science can never say anything about “reality-in-itself.”¹¹⁶

John Wheeler has also explored possible implications of quantum mechanics in cosmology, especially in reference to origination. Recall that Wheeler makes much of the

¹¹³Ibid., 161-62.

¹¹⁴Ibid., 162.

¹¹⁵Ibid., 167.

¹¹⁶Ibid., 170.

orthodox view that “Until the act of detection the phenomenon-to-be is not yet a phenomenon.”¹¹⁷ The importance of the “act of detection” (observation) seems even more important in light of Wheeler’s famous delayed-choice experiments, a variation of the two-slit experiment in which the experimental set-up is altered while quantum particles are in transit across the apparatus. John Gribbin’s explanation of this experiment is very helpful.

Wheeler started from the proven fact that if photons are fired through the experiment one at a time, they still build up an interference pattern on the other side [i.e., on the detection screen], as if they had gone through both holes at once and interfered with themselves. But if the experiment is set up so that a detector monitors which hole each photon goes through, each photon is indeed observed to be going through only one hole, and there is no interference pattern. Wheeler pointed out that it would be possible to set up a detector not at the holes themselves, but intermediate between the two holes and the ultimate detector screen, looking to see which route a particular photon was taking after it had passed the two holes but before it arrived at the screen. Quantum theory says that if we choose to turn this new detector off and not look at the photons, there will be no interference pattern. But if we look at the photons to see which hole they went through, even if we look [less than a microsecond] *after* they have gone through the hole, there will be no interference pattern. The ‘delayed choice’ comes into the story because we can make the decision whether or not to look at the photon (or the decision can be made at random by a fast computer) *after* the photon has already passed through the hole(s). The decision we make, according to [the Copenhagen rendering of] quantum theory, seems to affect how the photon behaved at the time it was passing through the hole(s), a tiny fraction of a second in the past.¹¹⁸

According to many commentators, when Wheeler’s proposal is put to the test in the laboratory the results indicate that we decide the past by present observation. Taking this consensus as a mandate for extension of his theory into ultimate cosmological origins, Wheeler says that though the delayed-choice experiments involve only a fraction of a microsecond’s delay and a total distance of a mere thirty meters, in principle the delay may as well have been billions of years and the distance billions of light years. From this Wheeler moves to a radical conclusion about the past.

It is wrong to think of that past as ‘already existing’ in all detail. The ‘past’ is theory. The past has no existence except as it is recorded in the present. By deciding

¹¹⁷Wheeler, “Law without Law,” 189.

¹¹⁸John Gribbin, *Q is for Quantum: An Encyclopedia of Particle Physics* (New York: Free Press, 1998), s.v. “delayed choice experiment.”

what questions our quantum registering equipment shall put in the present we have an undeniable choice in what we have the right to say about the past. . . . The phenomena called into being by these decisions reach backward in time in their consequences . . . back even to the earliest days of the universe. . . . Useful as it is under everyday circumstances to say that the world exists ‘out there’ independent of us, that view can no longer be upheld. There is a strange sense in which this is a ‘participatory universe.’¹¹⁹

Wheeler brings this speculation to a crescendo when he asks if the term “Big Bang” might be a shorthand way of describing what untold billions of “elementary acts of observer-participancy” have brought about as they reach backward in time.¹²⁰ While he stops short of answering this question, one cannot help but believe Wheeler is calling for an atheistic conclusion to the question of the universe’s ultimate origin. If so, it is only by virtue of the wide popularity of the CI that he can present his case as a piece of science rather than particularly imaginative science *fiction*.

Taking a similar but less anthropocentric angle on a possible naturalistic explanation for the origin of the universe, Alan Guth says quantum physics may imply that the existence of the universe is inevitable.

While the attempts to describe the materialization of the universe from nothing remain highly speculative, they represent an exciting enlargement of the boundaries of science. If someday this program can be completed, it would mean that the existence and history of the universe could be explained by the underlying laws of nature. That is, the laws of [quantum] physics would imply the existence of the universe. We would have accomplished the spectacular goal of understanding why there is something rather than nothing—because, if this approach is right, perpetual ‘nothing’ is impossible.¹²¹

P. W. Atkins adopts a biblical meter when he says, “In the beginning there was nothing. Absolute void, not merely empty space.” Then came the natural “miracle” of creation. “By chance there was a fluctuation, and a set of points, emerging from nothing

¹¹⁹Wheeler, “Law without Law,” 194.

¹²⁰*Ibid.*, 196-97. In response to the idea that observation created the universe, John Bell asks, “Was the world wave function waiting to jump for thousands of millions of years until a single-celled living creature appeared? Or did it have to wait a little longer for some more highly qualified measurer – with a Ph.D.?” John Bell, “Quantum Mechanics for Cosmologists,” in *Speakable and Unspeakable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 117.

¹²¹Alan H. Guth, *The Inflationary Universe: The Quest for a New Theory of Cosmic Origins* (New York: Addison-Wesley, 1997), 276.

and taking their existence from the pattern they formed, defined a time.”¹²² As is standard in every appeal to quantum mechanical creation of the universe, Atkins claims that matter/anti-matter transitions illustrate acausal creation from nothing.¹²³

Perhaps the most significant of all proponents for a naturalistic, quantum mechanical origin for the universe is Quentin Smith. He boldly claims that quantum physics shows that “many particles” simply pop into existence without a cause.¹²⁴ In a 1996 speech delivered to the Atheist Alliance, Smith went so far as to argue that in light of quantum mechanics, “it is highly probable that a Universe with our characteristics will come into existence without a cause.”¹²⁵

Smith’s case hinges on the appeal to indeterminacy and acausality as supplied by the CI, especially its Uncertainty Principle. Recall that on the Copenhagen view, quantum uncertainty is not a reflection of our investigative limitations, but rather a reflection of genuine quantum indeterminacy. This in turn entails that quantum events are acausal. As noted above, Smith thinks one result of quantum acausality is the ability to get particles for free—the uncreated, naturalistic origin of material micro-reality. But how could such a process yield an entire universe? Smith realizes he needs to build up the argument for particle creation if he is to explain all of material reality, and so he offers two mathematical formulas to make his case. These are:

$$\Delta E \cdot \Delta t \geq h/4\pi \quad \text{and} \quad \Delta t \sim (h/4\pi) \Delta E$$

Smith first explains $\Delta E \cdot \Delta t \geq h/4\pi$, where $E \equiv$ energy, $t \equiv$ time and $h \equiv$ Planck’s constant.¹²⁶

¹²²P. W. Atkins, *Creation Revisited* (New York: W. H. Freeman & Company, 1992), 149.

¹²³*Ibid.*, 139.

¹²⁴Quentin Smith, “A Big Bang Cosmological Argument for God’s Nonexistence,” *Faith and Reason* 9 (1992): 217.

¹²⁵Quentin Smith, “Two Ways to Prove Atheism,” sec. 1 [on-line]; accessed 17 June 2005; available from http://www.infidels.org/library/modern/quentin_smith/atheism.html; Internet.

¹²⁶Planck’s constant is a value used to relate the particle nature of a quantum entity to its wave nature. See Gribbin, *Encyclopedia*, s. v. “Planck’s constant.”

This relation implies that if the energy of a particle is measured precisely, so that ΔE is made very small, the time at which the particle possesses this energy can be known only imprecisely, so that Δt is very large. Now if Δt is small enough, ΔE becomes so large that it becomes impossible in principle to determine if the law of energy conservation is violated.¹²⁷

What Smith has said here is that Δt and ΔE relate to one another as do the two far ends of a seesaw. When one value is brought close to the ground (measured precisely) the other is aloft (largely unknown). The important claim is that when we precisely measure the change in time, we are effectively ignorant about what changes of energy may be occurring, and that this might be an opening for fantastic violations of energy conservation.

Next, Smith explains his interpretation of $\Delta t \sim (h/4\pi) \Delta E$, which really just serves to make larger the opening he has attempted to make with his first equation.

During the interval of time $\Delta t \sim (h/4\pi) \Delta E$ this law [of energy conservation] is inapplicable and consequently an amount of energy ΔE can spontaneously come into existence and then (before the interval has elapsed) cease to exist. There is observational evidence, albeit indirect, that this uncaused emergence of energy or particles (notably virtual particles) frequently occurs.¹²⁸

Here Smith further explains what might go on while we are measuring Δt and thereby neglecting ΔE . During intervals of minutely short duration, Smith says ΔE can occur non-conservatively, which is to say energy is gotten free of charge and from nothing. Now this is a tricky matter. Smith is claiming that conservation is violated while we are not looking, and then claims there is indirect “observational evidence” for this operation, namely, in the formation of virtual particles. We might first ask what sense can be made of his claim that this violation of conservation is observable, even if only indirectly. The supposed violation is instantaneous, and occurs behind a veil thrown up by the fact we are observing Δt rather than ΔE . Furthermore, and this is a greater problem, the virtual particles that Smith claims arise due to violations of conservation are not created *ex ni-*

¹²⁷Quentin Smith, “The Uncaused Beginning of the Universe,” *Philosophy of Science* 55 (1988): 50.

¹²⁸Ibid.

hilo, but rather represent a transition from existing energy to matter.¹²⁹ Keith Ward expresses the difficulty for the sort of argument Smith makes.

On the quantum fluctuation hypothesis, the universe will only come into being if there exists an exactly balanced array of fundamental forces, an exactly specified probability of particular fluctuations occurring in this array, and an existent space-time in which fluctuations can occur. This is a very complex and finely tuned ‘nothing’!¹³⁰

Hence, the claim that quantum particles can be gotten for nothing and from nothing involves a bit of scientific smoke-and-mirror. The so-called acausal creation of virtual particles occurs in accordance with the regular laws governing the previously extant energy and matter of the system. Hence, neither acausality nor *creatio ex nihilo* is demonstrated in virtual particle production.

Further, Smith does not tell us how he can prove that the amount of virtual particles formed is disproportionate to the energy that was originally available, but on his assumptions it would have to be the case that more matter was purchased than conservation could have afforded. And to create an entire *universe* the energy violation would have to be terrific. His only evidence for this claim is that we lose track of ΔE when Δt is precisely measured, but, on the contrary, surely our ignorance of ΔE is no genuine proof that the conservation law suddenly stands down, and still less so dramatically as to produce the energy/matter required for the construction of an entire universe. It seems far more sensible to assume that ΔE is no covering for fanciful operations, and that the emergence of particles is exactly proportional to the amount of energy that was conservatively available to drive the emergence. On this assumption there is no violation of ther-

¹²⁹William Lane Craig, “The Beginning of the Universe,” in *Faith and Reason*, ed. Paul Helm (Oxford: Oxford University Press, 1999), 281.

¹³⁰Keith Ward, *God, Chance and Necessity* (Oxford: Oneworld Publications, 1996), 40. For similar arguments against “ex nihilo” as a true condition of quantum creation models, see Ian G. Barbour, *Nature, Human Nature, and God* (Minneapolis: Fortress Press, 2002), 115; Marcelo Gleiser, “The Three Origins: Cosmos, Life, and Mind,” in *Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity*, ed. John D. Barrow, Paul C. W. Davies, and Charles L. Harper (Cambridge: Cambridge University Press, 2004), 641; Corey, *God and the New Cosmology*, 43.

modynamic laws, nor is there grounds for citing indeterminacy, acausality, or *ex nihilo* “creation” of virtual particles.

In summary, I would like to cite Stanley Jaki’s assessment of the whole naturalistic universe-for-nothing argument. Note that his critique touches several different aspects of the CI.

[Scientists] took a basic consequence of quantum mechanics about the impossibility of measuring certain interactions with complete accuracy for the justification of the following proposition if not plain somersault in logic: an interaction that cannot be measured exactly, cannot take place exactly. . . . With little or no second thoughts on that incredible somersault, scientists quickly began to assume that ‘chance’ could supply the bits of energy or matter which, owing to the impossibility of exact measurement, could not be accounted for mathematically. This preposterousness—certainly indicative of an erstwhile blow to the human intellect—gained so much scientific respectability that twenty years later Hoyle and Cie could postulate the emergence out of nothing, at every second, of hydrogen atoms in quantities amounting to entire stars. They did not have to fear wholesale indignation within the world of science, already sold on the idea that cheating with energy and matter on a very small scale was in intellectually respectable procedure.¹³¹

As a whole, quantum cosmology is highly speculative and untested.¹³² One sometimes hears that it would take a particle-collider the size of the universe to put quantum cosmogonies to the empirical test. Furthermore, the fact that not all physicists and philosophers agree that quantum indeterminacy is accurately portrayed as evidence for quantum acausality (as per the CI) indicates that the so-called quantum acausal beginning of the universe is anything but a lock for scientific truth.¹³³ In fact, any reasonable accounting of the evidence shows up the sheer impossibility of getting a free universe from a bit of quantum magic.

Chapter Summary

From race relations to financial analysis, feminist apologetics to leadership

¹³¹Stanley L. Jaki, *The Savior of Science* (Grand Rapids: Eerdmans, 2000), 124.

¹³²John Earman and Jesus Mosterin, “A Critical Look at Inflationary Cosmology,” *Philosophy of Science* 66 (1999): 2.

¹³³R. Douglas Geivett, “The *Kalam* Cosmological Argument,” in *To Everyone an Answer: A Case for the Christian Worldview*, ed. Francis J. Beckwith et al. (Downers Grove, IL: InterVarsity, 2004), 72.

studies, from cosmology and on to human consciousness and the laws of logic, the Copenhagen interpretation of quantum physics is a major player in contemporary attempts at worldview construction. As demonstrated above, the role of the CI in such constructions varies from one application to the next.

In some cases, Copenhagen pillars such as acausality or complementarity simply serve as analogies for applications in non-physics spheres. The thought in such cases seems to be that if such unexpected qualities genuinely inhere the real physical world, surely we are right to posit analogous concepts outside the physical sciences. In other cases, core components of the CI are thought to have direct causal influence on objects and events of the macrophysical realm.

In any case, the CI is used to inform worldviews or slices of worldviews because it is presumed to be the uncontested interpretation of what is commonly touted as the most successful scientific theory in human history. For this reason it is important that representatives of the Christian worldview take the time to analyze this bit of scientific wonderment, especially insofar as it sets up tension or outright contradiction with major themes of the Christian worldview. I have not endeavored in this chapter to demonstrate that vital elements of the CI and their application are genuinely contradictory to Christianity. That is one of the tasks of chapter 5. Nevertheless, in closing this chapter, I would like to list some of the points on which such problems occur in preparation for the somewhat longer discussion to come. In brief, the following components and/or applications of the CI are problematic on a Christian view of the world.

First, the doctrine of complementarity, which is based on the supposition that quantum systems must be described by the wave-particle paradox, encourages the acceptance of contradictories as simultaneously feasible. Bohr himself celebrated this implication as a vital comportment with Eastern concepts that stress the mutuality of opposites. As I demonstrate more forcefully later, Bohr, Born, and Heisenberg all made statements

that indicate that complementarity had ramifications for truth-concepts not just in physics, but knowledge generally.

Second, the CI stresses that quantum physical reality is fundamentally indeterminate—that is, *acausal*—such that there is (a) no rationality to quantum behavior, and (b) no objective, definitive existence to quantum systems apart from acts of observation. In this chapter we saw that Copenhagen-aligned physicists such as John Wheeler openly wonder if this might mean that the universe itself was created by acts of creaturely observation. In Wheeler’s “participatory-universe” model, humans are world makers in a surprisingly unqualified sense. We also saw that some realists have taken the CI to be correct in its insistence that quantum events are genuinely irrational when judged by the standards of classical logic and on this basis have sought to recast the laws of logic in light of quantum strangeness.

Third, various interpreters have supposed that quantum realities, as defined by the CI, impinge on supra-quantum realities. For Kirill Ilinski, this means that quantum uncertainty, which is taken to be *ontological* rather than merely epistemological, is endogenous to the social sciences as well. For Friedrich Beck, quantum mechanical impingement on macroworld affairs means that human consciousness, described as a quantum effect, ought to operate above the overly narrow strictures of classical logic. “Either, or,” and “If, then,” logic is wrongfully eliminative of a whole host of middle-way possibilities.

Fourth, the loss of objectivity and the acceptance of paradox as a genuine feature of reality together speak powerfully against the possibility of metaphysical certainty and/or exclusivity. Feminists and race-rights advocates see this as a means of undermining the legitimacy of power structures built around gender, social, or race factors, but the fact is that this is an unsuitable basis for any human-rights campaign due to the defeasibility of relativism as a basis for moral obligation. The CI’s undermining of “objective reality” also plays into the hands of post-modernists and religious relativists. Heidegger

and Lyotard, as Norris and Plotnitski have noted, found elements of quantum theory (as per the CI) to be supportive of their programs. Zohar cited quantum theory's banishment of objective, correspondent truth as evidence that monotheism, which she reports to be a root of much evil, is *out* as a worldview option.

Fifth, the involvement of the CI in positivism insinuates that metaphysics is a dead project. Whatever cannot be observed cannot be a real component of the world we inhabit.

Sixth, the anti-realist, Kantian elements of the CI push vital metaphysical claims beyond knowledge and into the ethereal realm of unknown things-in-themselves. Disparate and contradictory metaphysical claims are simultaneously feasible due to complementarity as well as the sheer impossibility of evaluating noumenally-conditioned propositions. In this sense, the CI eliminates metaphysics by procuring the possibility that all metaphysical claims are true, which is the same as saying *none* are true.

Seventh, the CI's emphases on quantum acausality and uncertainty is thought by some to raise the possibility of arguing that the universe is simply a natural product of a chance physical event.

With Popper, I conclude that something *is* rotten in the state of Denmark. The CI is a study in irrationalist excess. Nevertheless, as the next chapter demonstrates, even the theologians among us are drawn to peer into the Copenhagen cauldron in search of the ingredients necessary to build better apologies for various Christian beliefs.

CHAPTER 4

APPLICATIONS OF THE COPENHAGEN INTERPRETATION IN METAPHYSICS AND THEOLOGY

Abner Shimony argues that scientific developments of the twentieth century gave rise to “experimental metaphysics,” by which he means to indicate that the purview of natural science has so deepened that now more than ever before it can be used to evaluate evidences for and against various metaphysical proposals. While we should not expect that the sciences can produce “straightforward and decisive resolution of metaphysical disputes,” we may nevertheless use the hypothetico-deductive method fruitfully as we attempt to adjudicate between competing metaphysical claimants.¹

In this chapter I will survey various avenues by which scientists, philosophers, and theologians have sought to apply the returns of “experimental metaphysics” as informed by the orthodox view of quantum physics. In each case, the applications are based on the presumption that the CI is the final, definitive, and only available interpretation of quantum physics.

Holism and Panpsychism

Some commentators believe that all macroscopic systems should be approached with a view toward discerning their quantum mechanical qualities since systems of every size are, at base, composed of quantum entities. This extends the range of implications exemplified by the so-called measurement problem in quantum physics,

¹Abner Shimony, “Search for a Worldview Which Can Accommodate Our Knowledge of Microphysics,” in *Philosophical Consequences of Quantum Theory: Reflections on Bell’s Theorem*, ed. James T. Cushing and Ernan McMullin (Notre Dame: University of Notre Dame Press, 1989), 26-27.

where macroscopic measuring devices become “entangled” (causally linked) with the quantum systems they are set to measure.² If all systems should be treated as quantum mechanical, entanglement is possible throughout the universe. Furthermore, entanglement becomes all the more important when physicists claim that non-locality conditions seem in principle to be possible even for quantum systems separated by vast reaches of space.³ Naturally, this emphasis on the far-reaching capacities of quantum entanglement leads to various holistic conceptions of the universe.

Richard Kitchener argues that holism has been present in the orthodox interpretation of quantum physics since Bohr himself articulated it in 1934, and that holism and process philosophies are the only sorts of metaphysic that are compatible with the new physics.⁴ David Bohm and B. J. Hiley, who offer a more classical alternative to Bohr’s interpretation of quantum mechanics that nonetheless stresses holism, agree with Kitchener’s assessment of Bohr. “In Bohr’s view, the universe is basically an unanalyzable whole, in which the notion of the separateness of particle and environment is an abstraction that has no content, except as an approximation that may be applied within the limit of Heisenberg’s principle.”⁵

In the work of Errol Harris, emphasis on a whole-over-part metaphysic leads to two important implications. First, all relations between particulars in the universe are internal rather than external.⁶ Second, the “unity of differences” requires a dynamic principle.

²Bernard d’Espagnat, *Veiled Reality: An Analysis of Present-Day Quantum Mechanical Concepts* (New York: Addison-Wesley, 1995), 158-59.

³Amir D. Aczel, *Entanglement: The Greatest Mystery in Physics* (New York: Four Walls Eight Windows, 2002), xi.

⁴Richard F. Kitchener, “Introduction: The World View of Contemporary Physics: Does It Need a New Metaphysics?” in *The World View of Contemporary Physics: Does it Need a New Metaphysics?* ed. Richard F. Kitchener (Albany: State University of New York Press, 1988), 15.

⁵David Bohm and B. J. Hiley, “The de Broglie Pilot Wave Theory and the Further Development of New Insights Arising Out of It,” *Foundations of Physics* 12 (1982): 1002.

⁶Errol E. Harris, “Contemporary Physics and Dialectical Holism,” in *The World View of Con-*

Each [constituent of the universe] relates to its other: first, as opposite by negating and excluding it; second, as complementary, or contrary; and third as a distinct exemplification of the ordering principle governing the system to which both belong. Yet the internal character of each depends on its relation to the others. Thus, what each is implies what it is not, and vice versa. Consequently, each is implicitly the whole; each represents the whole, as it were, from its special viewpoint and, therefore is, in itself, a whole of a sort and at the particular level at which the universal principle of order is being expressed in it.⁷

Kitchener concludes that Harris is proposing a dialectical holism that is fundamentally Hegelian.⁸ I would add to this that Harris's work depends on acceptance of several doctrines in the CI, most notably the measurement problem.

Paul Teller argues that quantum physics *displaces* particularistic conceptions of the world and substantiates a metaphysic of relational holism, which among other things means that local causality is an invalid concept and that the demand that correlations be explained causally must be dropped.⁹ Don Howard similarly adopts what he calls "radical ontological holism" after considering and rejecting the separability principle, where the separability principle is defined as follows. "It asserts that the contents of any two regions of space-time separated by a nonvanishing spatio-temporal interval constitute separable physical systems, in the sense that (1) each possesses its own, distinct physical state, and (2) the joint state of the two systems is wholly determined by these separate states."¹⁰

Nevertheless, Howard maintains that a "contextual criterion of individuation" operates, thus allowing that any two systems can be distinguished from the viewpoint of certain of their interactions, while they are conversely treated as but one system from an-

temporary Physics: Does It Need a New Metaphysics? ed. Richard F. Kitchener (Albany: State University of New York Press, 1988), 161.

⁷Ibid., 163.

⁸Kitchener, "Introduction," 15.

⁹Paul Teller, "Relativity, Relational Holism, and the Bell Inequalities," in *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*, ed. James T. Cushing and Ernan McMullin (Notre Dame: University of Notre Dame Press, 1989), 214-23.

¹⁰Don Howard, "Holism, Separability, and the Metaphysical Implications of the Bell Experiments," in *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*, ed. James T. Cushing and Ernan McMullin (Notre Dame: University of Notre Dame Press, 1989), 225-26.

other viewpoint.¹¹ Howard admits his proposal may be “woolly-headed” speculation, but says such speculation is the very sort of thing called for by the task of formulating a new metaphysic.¹²

Menas Kafatos and Robert Nadeau likewise argue that non-locality and entanglement entail radical ontological holism, as vividly expressed in the following passage.

Virtually everything in our immediate physical environment is made up of quanta that have been interacting with other quanta in this manner from the Big-Bang to the present. The atoms in our bodies are made up of particles that were once in close proximity to the cosmic fireball, and other particles that interacted at that time in a single quantum state can be found in the most distant star. This means, however strange or bizarre it might seem, that the quanta that make up our bodies are as much a part of a unified system as the photons propagating in opposite directions in the Aspect experiments. Thus non-locality, or non-separability, in these experiments translates into the vastly grander notion of non-locality, or non-separability, as factual conditions of the entire universe.¹³

Kafatos and Nadeau believe this has many important metaphysical ramifications, including that “human consciousness participates in the life of the cosmos” in causative ways.¹⁴ Importantly, they also believe that quantum physics entails the rejection of the Judeo-Christian presuppositions that classically served as important grounds for the scientific endeavor, namely, that human minds participate in the mind of God and are capable of interpreting in ordinary language and concepts a natural world created as “a transcript of the willful and directed purpose of Jehovah”¹⁵

Fritjof Capra is yet another commentator who concludes that quantum physics reveals a fundamentally holistic universe in which “there are no parts at all.”¹⁶ For hu-

¹¹Ibid., 250.

¹²Ibid., 253.

¹³Menas Kafatos and Robert Nadeau, *The Conscious Universe: Part and Whole in Modern Physical Theory* (New York: Springer-Verlag, 1990), 73. Recall that the Aspect experiments, as discussed in chapter 2, seemingly verified quantum non-locality as a genuine reality.

¹⁴Ibid., 108-09.

¹⁵Ibid., 100.

¹⁶Fritjof Capra, *The Tao of Physics: An Exploration of the Parallels Between Modern Physics and Eastern Mysticism*, 4th ed. (Boston: Shambhala, 2000), 68, 329-30.

mans particularly, Capra believes we must realize that individuals and societies are “embedded” in nature’s cyclical processes.¹⁷ Capra traces the development of holism in physics directly to the rapid-fire revolution propagated throughout the 1920s, when Bohr and his colleagues broke with traditional views and started the physics and philosophy worlds off on a path to holism.¹⁸ If Bohr started us down this path, Capra is eager to lead us to its end—where holism transcends scientific fact and thus becomes the foundation for cosmic religion, or as Capra calls it, an ecological worldview. “Ultimately, deep ecological awareness is spiritual or religious awareness. When the concept of the human spirit is understood as the mode of consciousness in which the individual feels connected to the cosmos as a whole . . . it becomes clear that ecological awareness is spiritual in its deepest essence.”¹⁹

The holism presented in the CI has close affinity with the doctrine of complementarity, which opens up important possibilities in discussions of the mind-matter relation. K. V. Laurikainen explains that Wolfgang Pauli, a key member of the fellowship of physicists who founded the CI, rejected materialism and Cartesian dualism in favor of a conception that would treat mind (spirit) and matter as complementaries. In Laurikainen’s words, Pauli wanted to treat matter and psyche as a “whole” formed by a complementarity similar to “that between the position coordinate x and its conjugate momentum p_x in quantum mechanics.”²⁰ In all, Pauli’s discussion of the complementarity of mind and matter is connected with his “emphasis on the *irrationality* of reality and the essential *role of the unconscious* when forming a picture of the world.”²¹

¹⁷Fritjof Capra, “The Role of Physics in the Current Change of Paradigms,” in *The World View of Contemporary Physics: Does It Need a New Metaphysics?* ed. Richard F. Kitchener (Albany: State University of New York Press, 1988), 145.

¹⁸Ibid., 147.

¹⁹Ibid., 145-46.

²⁰K. V. Laurikainen, “Wolfgang Pauli’s Conception of Reality,” in *Symposium on the Foundations of Modern Physics: The Copenhagen Interpretation 60 years After the Como Lecture*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific Publishing, 1987), 220-21.

²¹Ibid., 221.

Ervin Laszlo specifically cites quantum physics as the source for the doctrines of complementarity and holism he appeals to in his treatment of the mind-matter relation, which has clear affinity with process philosophy.

The metaphysics of universal connectivity is ontologically unitary but not categorically monistic: in it both *psyche* and *physis* are defining features. Such a concept is not classically dualistic, for matter and mind are viewed as defining, but not as disjunctive, features—they are complementary aspects of the same evolving reality. These aspects are universal: in the interactively evolving universe matter is not limited to particles, and mind is not limited to organisms. Physical reality evolves into all of reality, and mind is an element throughout evolving reality. The universe is ‘bipolar’: *matter* (in the form of matter-like bound-energy entities) and *mind* (as manifested in the stream of lived experience), are distinct but complementary aspects.²²

It seems that a basic panpsychism is shaping up here. As Laurikainen explains it, panpsychism is the view that mind/spirit and matter are two distinct elements of reality that cannot exist apart from one another, an implication of which is that all events are both material and mental.²³ Laurikainen says Pauli himself took this view, insisting that mind/spirit relates to matter in a complementary fashion, as do particles and waves in quantum theory.²⁴

Danah Zohar notes that panpsychism is gaining in popularity due to developments in modern physics and the demise of traditional Western religion. While Zohar notes that the new brand of panpsychism is not so radical as past forms, which included such beliefs as that mountains have souls, the current “limited” panpsychism is nevertheless a marked departure from traditional conceptions of the mind-matter relation.

The logic employed in limited Panpsychism begins with a set of obvious facts. There is only one basic kind of matter, all things—animate and inanimate—are made of it, some of this matter has the undoubted capacity for conscious life, and at the quantum level at least there is a creative dialogue between matter and con-

²²Ervin Laszlo, *The Connectivity Hypothesis: Foundations of an Integral Science of Quantum, Cosmos, Life, and Consciousness* (Albany: State University of New York Press, 2003), 110-11.

²³K. V. Laurikainen, “Quantum Theory and the Problem of Free Will,” in *Symposium on the Foundations of Modern Physics 1990: Quantum Theory of Measurement and Related Philosophical Problems*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific, 1991), 221.

²⁴Ibid.

sciousness. This dialogue means that the observer's conscious mind actually influences the material development of that which he observes.²⁵

Here again we see that the CI's claim that unobserved quantum systems are ontologically indeterminate leads to the conclusion that the human observer is a world-making participant and not simply an observer of realities that exist apart from himself.

Assessing the case for holism and panpsychism. There is at least one definitive reason to deny that quantum entanglement justifies all the holistic and panpsychical entailments discussed above: entanglement is not all it is cracked up to be. While experiments such as those carried out by Aspect and his colleagues include highly controlled conditions that keep entangled particles from being interfered with by other objects, in real life any two entangled particles will at every instant be jostled by countless other particles. The net effect of this real-world interference factor is that the magnitude of entanglement between any two quantum particles, G and H , is immediately lessened by interaction with a host of other nearby particles, I, J, K , and so on. In the breadth of a microsecond particle G , for instance, has become entangled with new partners, such that its former alliance with H is forgotten. In other words, entanglement between any pair of quantum particles under real world conditions is fleeting and soon becomes non-existent.²⁶ Anton Zeilinger even goes so far as to say the entanglement between two particles is broken just as soon as one of them interacts with another system (whether the physicist's detector or another particle).²⁷ If Zeilinger is correct, this means entanglement never spans more than two particles. In this light, it is clearly unwarranted to say, as for instance Kafatos and Nadeau do above, that the quantum particles in our minds are entangled with particles with which they were affiliated in the early state of the universe.

²⁵Danah Zohar, *The Quantum Self: Human Nature and Consciousness Defined by the New Physics* (New York: Quill, 1990), 56.

²⁶Brian Greene, *The Fabric of the Cosmos: Space, Time, and the Texture of Reality* (New York: Knopf, 2004), 122-23.

²⁷Zeilinger quoted in Arthur Zajonc, *The New Physics and Cosmology: Dialogues with the Dalai Lama* (Oxford: Oxford University Press, 2004), 28.

The sort of entanglement required to warrant holism and panpsychism is clearly an ideal that cannot be instantiated in the real world, where each micron of space and matter is crammed with quantum particles that are constantly careening off one another and erasing any near-past, let alone far-past, entanglements.

Quantum Physics and Purported Eastern Parallels

Perhaps the most common non-science application of quantum physics is found in literature propounding Eastern and New Age concepts of religion and world. Capra dares even to say that quantum physics *forces* us to see the world from an Eastern worldview perspective.²⁸ Gary Zukav names the CI specifically as the agent that has initiated a “monumental reunion” between the rational and irrational aspects of our psyches.²⁹ While Capra and Zukav are perhaps sometimes bolder than they ought to be as they appeal to quantum science to justify their New Age programs, in reality they are simply building on a line of implication laid down by Bohr himself, who suggested that atomic theory displays key parallels to the epistemologies of Buddha and Lao Tzu.³⁰ Recall that Bohr adopted the Yin-Yang symbol of Taois for his coat of arms, which symbolizes a whole created by two complementary (contradictory) elements.³¹ Werner Heisenberg also stated a belief in a “certain relationship” between Eastern philosophies and “the philosophical substance of quantum theory.”³²

That “certain relationship” is the mutual emphasis on irrationality as a genuine characteristic of the real world. Western suppression of irrationality causes the CI to be

²⁸Capra, *Tao*, 18.

²⁹Gary Zukav, *The Dancing Wu Li Masters: An Overview of the New Physics* (New York: William Morrow and Company, 1979), 62.

³⁰Niels Bohr, *Atomic Physics and Human Knowledge* (New York: John Wiley & Sons, 1958), 19-20.

³¹Laurikainen, “Quantum Theory,” 221.

³²Werner Heisenberg, *Physics and Philosophy: The Revolution in Modern Science*, vol. 19 of *World Perspectives*, ed. Ruth Nanda Anshen (New York: Harper and Brothers, 1958), 202.

problematic, says Laurikainen, but Eastern perspectives can help us overcome this tendency so that we may accept as real the fundamentally irrational world opened to us by the orthodox interpretation of quantum physics.³³ Interestingly, he says the tendency for Christian theologians to be closed to such matters as raised in quantum theory has encouraged many people to reject Western concepts in favor of Eastern views.³⁴

Buddhism and Quantum Mechanics

Of all the Eastern worldviews that have gained a broader hearing based on developments in quantum physics, none has enjoyed so spectacular a boost in scientifically sanctioned credence as Middle (Madhyamika) Buddhism. The key philosophical tenet of Middle Buddhism is the principle of emptiness. This principle says nothing has independent or inherent existence, i.e. exists apart from mind and knowing.³⁵ In the absence of a knowing mind, the external world can only have a minimalist existence. Failure to recognize this, say Middle Buddhists, causes us to believe mistakenly in inherent existence, which in turn opens us up to all manner of pain and suffering that come at the hands of craving and aversion.³⁶

The parallels the emptiness principle has with the CI's claim that the wave-function collapses during acts of measurement are clear. After all, according to the CI, quantum systems either do not exist or exist only in an indefinite state of superposition until forced to take on concrete reality by the act of measurement. Trinh Xuan Thuan explains the link between Middle Buddhism and quantum physics in the following way.

³³Laurikainen, "Wolfgang Pauli's Conception of Reality," 226.

³⁴Laurikainen, "Quantum Theory," 220.

³⁵Victor Mansfield, "Possible Worlds, Quantum Mechanics, and Middle Way Buddhism," in *Symposium on the Foundations of Modern Physics 1990: Quantum Theory of Measurement and Related Philosophical Problems*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific, 1991), 251-52. Mansfield also says that by rejecting "inherent existence," Middle Buddhism rejects physical realism and common-sense realism. This of course is another point Middle Buddhism has in common with the CI. *Ibid.*, 256.

³⁶*Ibid.*, 252.

Up through the nineteenth century, classical science argued that objects had an intrinsic existence governed by well-determined laws of cause and effect. But quantum mechanics . . . seriously undermined the idea that the basic ingredients of matter have such a definite existence, and also raised doubts about whether the world was governed by strict rules of cause and effect. The Buddhist idea of emptiness seems to be in harmony with the quantum view of reality.³⁷

Thuan and co-author Matthieu Ricard clearly have in mind the *orthodox* rendering of quantum physics, as Ricard makes clear in his claim that Heisenberg's objections to Einstein's EPR paper could have been written by a Buddhist philosopher.³⁸

William Ames agrees with Thuan and Ricard that Middle Buddhism has many "very similar ideas," but notes that Middle Buddhism is more thorough than quantum theory in its emphasis on the intrinsic emptiness of unobserved systems, and that its version of the "participatory universe" is likewise more thoroughgoing.³⁹ Hence, for Ames at least, the Copenhagen doctrines may start us down the Buddhist track, but it will take faith to complete the journey.

Lobsang Yeshe Tenzin Gyatso, the current Dalai Lama, commenting on the parallels between Bohr's take on quantum measurement and Middle Buddhist distinctions among truth types, says the following:

[Bohr's position] seems to be analogous to the distinction between ultimate and conventional truth within the Madyamika view. In terms of ultimate reality, you cannot posit anything at all as existing from its own side, by its own inherent nature—not even that emptiness of inherent existence itself exists. . . . In Buddhism, emptiness of inherent existence is the basis for the appearances of conventional phenomena.

When dialogue partner Piet Hut responds to this statement by saying that physics now indicates that there is no possibility of finding ultimate reality, the Dalai Lama says, "It's the same in Buddhism. If the ultimate nature of a phenomenon were to exist, it could be found. You don't find it; therefore it doesn't exist."⁴⁰ Just as in the CI, ultimate

³⁷Matthieu Ricard and Trinh Xuan Thuan, *The Quantum and the Lotus* (New York: Crown Publishers, 2001), 13.

³⁸*Ibid.*, 84.

³⁹William L. Ames, "Emptiness and Quantum Theory," in *Buddhism & Science: Breaking New Ground*, ed. B. Alan Wallace (New York: Columbia University Press, 2003), 301-02.

⁴⁰Zajonc, *The New Physics*, 152-54.

physical reality is in principle hidden from our view because it is somehow outside the realm of phenomena and conceptualization.

D. S. Kothari says the core spiritual and ethical insights of the Upanishads, Buddhism, and Jainism rely on the complementarity approach, which enables people to comprehend apparently contradictory viewpoints.

These [contrary viewpoints], on deeper understanding, may be found to be complementary and mutually illuminating—the two opposing contradictory aspects being parts of a ‘totality,’ seen from different perspectives. It allows for the possibility of accommodating widely divergent human experiences into an underlying harmony, and bringing to light new social and ethical vistas for exploration and for alleviation of human suffering.⁴¹

Kothari goes on to claim that quantum physics embodies the same logic as is found in Jainism’s Syādvāda logic, which asserts that knowledge is impossible unless one denies absolutes.⁴² One wonders if this is presented as absolutely true, but in any case it is clear that the emphasis on the incomprehensibility of the universe found in the CI marks a certain match between significant lines of Eastern thought and contemporary quantum physics. Wesley Wildman says the CI implies “cosmic absurdity,” which means the intelligibility of the universe is surrendered. This view is “affirmed systematically” in Vedānta philosophy, Middle Buddhism, and many other Buddhist traditions that “use the conjunction of apparently contradictory statements as a form of reference to ‘states of affairs’ essentially beyond categorical experience, and so beyond discussion.”⁴³

Non-Western worldviews are increasingly propounded in our nation’s primary and secondary school curricula. This is especially the case where Eastern views seem to be legitimated by the deliverances of quantum science. M. Jayne Fleener, who develops

⁴¹D. S. Kothari, “The Complementarity Principle and Eastern Philosophy,” in *Niels Bohr: A Centenary Volume*, ed. A. P. French and P. J. Kennedy (Cambridge, MA: Harvard University Press, 1985), 325.

⁴²*Ibid.*, 326.

⁴³Wesley J. Wildman, “Evaluating the Teleological Argument for Divine Action,” in *Evolutionary and Molecular Biology: Scientific Perspectives on Divine Action*, ed. Robert John Russell, William R. Stoeger, and Francisco J. Ayala (Vatican City: Vatican Observatory Publications, 1998), 150.

guidelines for educational curricula, celebrates quantum physics and the sense of emptiness it entails because it provides a “way of seeing” that comports with Buddhist concepts encouraging “surrender to uncertainty,” “tolerance for ambiguity and diversity,” and a sense of interconnected wholeness.⁴⁴

The East and Quantum Physics: An Assessment

While there are obvious similarities between Eastern thought and Bohr’s philosophy of quantum physics—similarities Bohr himself was eager to stress—popular accounts commonly exaggerate the extent to which developments in physics verify the Eastern outlook: key differences are downplayed or ignored, mere analogy is falsely presented as justifying grounds, and an Eastern apologetic agenda drives the arguments beyond their justified reach.⁴⁵ Physicist Victor Stenger singles out fellow physicist Capra as the chief exemplar of this behavior, noting that he meanders randomly through Eastern literature in search of anything resembling the new physics.⁴⁶ Zukav is a bit more cautious, Stenger believes, but he nevertheless ends up being “bamboozled by the numerous oversold and undersupported [sic] claims” made for quantum physics.⁴⁷

Alan Wallace, who clearly sympathizes with the Buddhist worldview, warns against a sort of Buddhism-of-the-gaps fallacy that apologists may be crafting by their

⁴⁴M. Jayne Fleener, *Curriculum Dynamics: Recreating Heart* (New York: Peter Lang, 2002), 164, 186-87.

⁴⁵Michel Bitbol, “A Cure for Metaphysical Illusions: Kant, Quantum Mechanics, and Madhyamaka,” in *Buddhism & Science: Breaking New Ground*, ed. B. Alan Wallace (New York: Columbia University Press, 2003), 326-27. Dana Edgar Bible notes that Capra and other Eastern apologists have “played loose” and have been “overly reductionistic” with the links between quantum physics and Eastern thought. Dana Edgar Bible, “Metaphysical Implications of the New Physics: An Assessment of Christian and Non-Christian Views” (Ph.D. diss., Southwestern Baptist Theological Seminary, 1986), 153-63.

⁴⁶Victor J. Stenger, *Physics and Psychics: The Search for a World Beyond the Senses* (Buffalo: Prometheus, 1990), 265. Ian Barbour also criticizes Capra’s Eastern apologetic. “Capra has overstressed the similarities and virtually ignored the *differences* between the two disciplines. Often he finds a parallel by comparing particular terms or concepts, abstracted from the wider contexts that are radically different.” From Ian Barbour, *Religion in an Age of Science: The Gifford Lectures 1989-1991* (San Francisco: Harper & Row, 1990), 1:119.

⁴⁷Stenger, *Physics*, 265.

appeal to dominant views of quantum physics. If current convictions regarding the physics are overturned in the future, what becomes of the Buddhist apologetic?⁴⁸ While I do not share Wallace's concern for the preservation of viability in Buddhist apologetics, I appreciate his recognition that contemporary interpretations of quantum physics are anything but inviolable in view of the underdevelopment of quantum theory. I conclude that the CI, by design, does have significant affinities for Eastern thought, but that discussions of the affinities are commonly marked by tendentiousness and exaggeration.

Quantum Ontology

The orthodox interpretation of quantum physics has ramifications for ontology largely because it insists that quantum theory is complete, such that no supplementations that could clear away current conceptual difficulties are expected to come with further investigation. Laurikainen explains that the founding theorists of the CI emphasized the completeness claim in order to put across as necessary their call for new concepts of causality and ontology.⁴⁹ However, in a significant sense the "new ontology" called for by the CI is actually *anti*-ontology. Henry Stapp explains the viewpoint of Copenhagen theorists.

In their view the new theoretical entities upon which physicists base their understanding of quantum phenomena must be interpreted not as theoretical counterparts of entities existing in nature itself, but merely as elements of a computational procedure that allows scientists to form expectations pertaining to observations that appear under certain kinds of conditions.⁵⁰

Why so? Simply this: any attempt to ontologize the theoretical posits of the orthodox theory result in patent absurdities such as Everett's many-worlds theory or physi-

⁴⁸Alan B. Wallace, *Choosing Reality: A Buddhist View of Physics and the Mind* (Ithaca, NY: Snow Lion, 1996), 10.

⁴⁹Laurikainen, "Quantum Theory," 218.

⁵⁰Henry P. Stapp, "Quantum Nonlocality and the Description of Nature," in *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*, ed. James T. Cushing and Ernan McMullin (Notre Dame: University of Notre Dame Press, 1989), 154.

cal impossibilities entailed by non-locality, such as superluminal influences.⁵¹

Despite the above, Stapp is willing to identify Heisenberg's "actual-event ontology" as the Copenhagen ontology.

According to this proposal, the probability amplitude of quantum theory corresponds to an *objective tendency* or 'potentia' for the occurrence of an actual event. This event effectively selects some particular macroscopic response of the measuring device from among the possibilities that were allowed prior to this event.⁵²

Here we see the vital interaction between the measuring device, whose operating conditions are dictated by human decision, and the measured quantum system. Quantum ontological reality is defined by such interactions. Stapp goes on to argue that all of this implies a kind of fusion between the mental and physical aspects of nature.

In the Heisenberg ontology, the real world of classical physics is transformed into a world of potentialities, which condition, but do not control, the world of actual events. These events, or acts, create the actual form of the evolving universe by deciding between the possibilities created by the evolving potentialities. These creative acts stand outside space-time and presumably create all space-time relationships. Human mental acts belong to this world of creative acts, but do not exhaust it.⁵³

The Heisenberg ontology, in keeping with obfuscationist themes throughout the CI, effectively pushes observation-independent reality out of our purview, for though quantum "potentia" exist, quantum phenomena are not actual until observation occurs. The "real world out there," independent of human acts of observation, is in some significant sense potential rather than actual. Here again we see that the CI is significantly Kantian. Things-in-themselves are simply unknown to us, for as soon as we endeavor to observe reality we find that we have helped contrive it.

⁵¹Ibid., 155. See also, Henry P. Stapp, "Quantum Theory and the Physicist's Conception of Nature: Philosophical Implications of Bell's Theorem," in *The World View of Contemporary Physics: Does It Need a New Metaphysics?* ed. Richard F. Kitchener (Albany: State University of New York Press, 1988), 44-45.

⁵²Stapp, "Quantum Theory," 41-42.

⁵³Ibid., 56-57.

Quantum Physics and Theology

Insomuch as quantum theory seems at odds with the materialistic, mechanistic excesses to which the Newtonian worldview was sometimes taken, it provides an opening for teleology to reenter the scientific discussion.⁵⁴ Furthermore, theology itself seems to be back on the table, for no longer can the naturalist cite unfringeable mechanical laws as proof that God cannot be involved in the world.⁵⁵ C. S. Lewis suggests that quantum indeterminacy, though it may prove to be merely a product of current ignorance, may open the door to a “sub-natural” realm where events do not causally interlock with one another. If the door to the sub-natural is open, Lewis suspects we are justified to think that the door to the supernatural is likewise opened.⁵⁶ Robert Webber believes quantum theory’s emphasis on holism and mystery (note that these are traits specifically of the CI) points us to the theologies of the early church.⁵⁷ Below I will survey the various ways theologians and other commentators have sought to employ current quantum mechanical theory as a means of justifying key theological concerns, especially free will and the possibility of divine action in the world.

Quantum Physics and Free Will

Laurikainen explains that the quantum irrationality described by Pauli, which is in keeping with the overall Copenhagen emphasis on quantum acausality, implies that freedom is a basic feature of the world.⁵⁸ Commentators picked up on this theme almost as soon as Pauli and others expressed it. Several who wrote just as the CI was coming off the presses and into prominence announced that quantum physics had saved human free-

⁵⁴Laurikainen, “Quantum Theory,” 222.

⁵⁵John Polkinghorne, *Science and the Trinity: The Christian Encounter with Reality* (New Haven, CT: Yale University Press, 2004), 5.

⁵⁶C. S. Lewis, *Miracles: A Preliminary Study* (San Francisco: HarperCollins, 1974), 19-20.

⁵⁷Robert Webber, *Ancient-Future Faith: Rethinking Evangelicalism for a Postmodern World* (Grand Rapids: Baker, 1999), 22.

⁵⁸Laurikainen, “Quantum Theory,” 217.

dom. A. S. Eddington, an early champion of Bohr's work, wrote in 1928 that the future is a combination of causal influences and completely unpredictable elements.⁵⁹ Several years later Arthur Compton celebrated quantum indeterminacy because it overturned the Newtonian challenge to human freedom.⁶⁰ Jeffrey Satinover is convinced that quantum physics secures the reality of freedom in the world, but he is not sure exactly who or what it is that is free. "What the quantum foundation of life tells me is this: The future has not yet been written. . . . I don't know whose freedom it really is, if anyone's, but I am convinced it is there and that it is woven into every fiber—every tubule, I suppose I should say—of my being, even if one calls it 'chance'." ⁶¹

A number of Christian thinkers have been eager to explore the possibilities of a quantum-based argument for human freedom. G. E. M. Anscombe argues that while physical indeterminism as propounded by quantum theory is not in and of itself sufficient to secure human freedom, it is nevertheless a necessary component of reality if such freedom is to be a genuine aspect of our world.⁶² As with Anscombe, John Polkinghorne favors the Copenhagen view that quantum indeterminacy is a matter of ontology rather than current ignorance, and on this basis argues that the future is open.⁶³ Arthur Peacocke shares Anscombe and Polkinghorne's hope in the quantum-based argument for freedom, and helpfully explains it as follows:

On this, to some no doubt revisionary, view God bestows a certain autonomy not only on human beings . . . but also on the natural order as such to develop in ways that God chooses not to control in detail. God allows a degree of open-endedness and flexibility in nature, and this becomes the natural, structural basis for the flexi-

⁵⁹A. S. Eddington, *The Nature of the Physical World* (New York: Macmillan, 1928), 294-95.

⁶⁰Arthur H. Compton, *The Freedom of Man* (New Haven, CT: Yale University Press, 1935), 29.

⁶¹Jeffrey Satinover, *The Quantum Brain: The Search for Freedom and the Next Generation of Man* (New York: John Wiley & Sons, 2001), 223.

⁶²G. E. M. Anscombe, "Causality and Determination," in *Causation and Conditionals*, ed. Ernest Sosa (Oxford: Oxford University Press, 1975), 79.

⁶³Polkinghorne, *Science and the Trinity*, 79-80.

bility of conscious organisms and, in due course and more speculatively, possibly for the freedom of the human-brain-in-the-human-body, that is, of persons.⁶⁴

Peacocke elsewhere explains that one outcome of quantum freedom is that God's action in the world has an "exploratory character" because the quantum indeterminacies purchase so impressive a degree of open-endedness that not even God can ensure specific outcomes.⁶⁵

John Jefferson Davis appeals to the CI's emphasis on "the role of experimental measurement in specifying the dynamic attributes of a quantum entity" and its postulation that present choices affect near-past events as justification for his reformation of the traditional understandings of the biblical doctrine of predestination.⁶⁶ In his words, "election is seen as a dynamic rather than as a static attribute in time, integrally tied to the 'experimental measurement' context of faith and conversion which gives it its full actuality and definition."⁶⁷ Davis contends that historic formulations of predestination have tended to abstract the doctrine from its proper soteriological context and place it instead in the foreign a priori framework of the eternal decrees.⁶⁸

From the perspective of the Copenhagen analogy being argued here, such an abstraction is illegitimate, since election and predestination are categories that have full actuality and definition only in the 'experimental' context of conversion and faith. By keeping the categories of predestination and election more closely tied to their New Testament contexts of conversion and faith, the problems of fatalism and sincerity of the offer can be mitigated if not avoided altogether.⁶⁹

Thus, on Davis's accounting, election becomes 'a determinate attribute' for an

⁶⁴Arthur Peacocke, "God's Interaction with the World: The Implications of Deterministic 'Chaos' and of Interconnected and Interdependent Complexity," in *Chaos and Complexity: Scientific Perspectives on Divine Action*, ed. Robert John Russell, Nancy Murphy, and Arthur Peacocke (Vatican City: Vatican Observatory Publications, 1995), 281.

⁶⁵Arthur Peacocke, *Theology for a Scientific Age: Being and Becoming – Natural, Divine and Human*, 2nd ed. (Minneapolis: Fortress Press, 1993), 157.

⁶⁶John Jefferson Davis, *The Frontiers of Science and Faith: Examining Questions from the Big Bang to the End of the Universe* (Downers Grove, IL: InterVarsity Press, 2002), 57-58.

⁶⁷Ibid., 58.

⁶⁸Ibid., 66.

⁶⁹Ibid.

individual person only at the time of their conversion (analogous to quantum measurement), never before. Of course, this means everyone who hears the gospel is “potentially elect prior to conversion.” What then becomes of biblical texts that seem to present election as eternal decree? Davis handles them in the following way.

Biblical texts such as Ephesians 1:4 that stress the temporal and eternal priority of the divine will in redemption are understood to be true in a potential and provisional sense prior to conversion; at the moment of saving faith this ‘already’ aspect of sovereign grace in the ‘past’ becomes actually and determinately true for the believer. Once conversion has taken place, it becomes the case that God has ‘already’ chosen the believer from ‘eternity past.’⁷⁰

As part of his proposed explanation of human agency, Davis suggests we discard the classical distinction between primary and secondary causation because this tends to minimize the validity of creaturely action. In place of this he posits something he calls “bilateral causation,” which suggests an “a posteriori determination of contingent events by acts of the divine will.”⁷¹ Davis expounds on this proposal in the following important paragraph.

The term *a posteriori* in the phrase ‘bilateral, a posteriori determination of contingent events’ (by the divine will) is intended to recognize creaturely initiative in the futuration of certain contingent events. In this model of God’s action in the world, God, at any given time $t1$, ‘sees’ the tendencies and potentials in a creature X —say, a radium nucleus—and because of this comprehensive knowledge of both the essential nature and potentials of the creature, and of the causal nexus in which it is embedded, knows that nucleus X is about to disintegrate at some time $t2$. By an a posteriori determination of his will, based on the immediate and comprehensive knowledge of vision, God then chooses to concur in the creaturely tendency and render certain the decay of the nucleus at time $t2$. The determination by the divine will is a posteriori in the sense that it is a ‘foreseen’ response to a set of tendencies *initiated within* the creature.⁷²

Davis admits that his emphasis on divine responsiveness makes God somewhat passive in His providential care for the world, but he thinks this is more suitable to the biblical concept of perfection than was the Thomistic notion that led to an unbiblical doc-

⁷⁰Ibid., 68.

⁷¹Ibid., 51.

⁷²Ibid., 52.

trine of divine unresponsiveness.⁷³ And of course creaturely freedom is preserved, which was Davis's aim from the outset.

Assessing the case for quantum-based free will. Christopher Norris criticizes Anscombe's argument for a quantum mechanical role in human freedom on two counts, and in my estimation his points count against all such arguments.

First, Norris notes that the argument hinges on the CI as if it were the only interpretive option in quantum mechanics. It is not, as I shall demonstrate later. Second, the argument depends on the feasibility of the link between quantum randomness and freedom of the will, but it seems clear that freedom and randomness are two entirely different things.⁷⁴ Karl Popper makes this second point as well. What we want to understand, he says, is how we are able to act "deliberately and rationally," not "unpredictably and in a chancelike fashion" as entailed by the appeal to indeterminism in quantum physics.⁷⁵

Physicist and Episcopal priest William Pollard addressed this problem half a century ago and concluded that quantum indeterminacy plays no part in the apology for human freedom.

I have grave doubts that there is any relationship at all between them. I cannot see how the existence of random chance fluctuations in the electrons, atoms, and molecules of which I am constituted can in any way contribute to an understanding of my subjective experience of my own freedom. The indeterminacies of quantum mechanics can lead only to the introduction of pure chance as in the flipping of a coin.⁷⁶

With Norris, Popper, and Pollard, I find the argument for human freedom based on quantum indeterminacy absolutely unviable. Even if scientists could establish a

⁷³Ibid., 53.

⁷⁴Christopher Norris, *Quantum Theory and the Flight from Realism: Philosophical Responses to Quantum Theory* (New York: Routledge, 2000), 146-47.

⁷⁵Karl Popper, *The Open Universe: An Argument for Indeterminism* (Totowa, NJ: Rowman and Littlefield, 1982), 126.

⁷⁶William G. Pollard, *Chance and Providence: God's Action in a World Governed by Scientific Law* (New York: Charles Scribner's Sons, 1958), 53-54.

clear avenue by which quantum indeterminacy could positively affect the outcomes of human mental deliberations, or again how it could without question win out against all other determinative factors present, it seems clear that irrational chance rather than rational choice would be the inevitable outcome. As the Christian doctrine of human freedom insists that we are capable of making *rational* choices between right and wrong, service of God or service of principalities of darkness, it seems clear that the Christian gains no ground by appealing to the CI of quantum mechanics.

Quantum Physics and Special Divine Agency

If the dominant philosophical construal of quantum physics indicates that quantum indeterminacy is ontologically genuine, might we say science has blasted open a crevasse in the anti-supernaturalistic edifice of natural science? Many theologians have thought so. One of the earliest proponents of the quantum mechanical argument for special divine action (hereafter SDA) was William Pollard, whom we cited above as denying that quantum indeterminacy could supply a basis for human freedom. Pollard begins his argument by claiming, as all proponents of quantum arguments for SDA must do, that quantum indeterminacy is a genuine reality and not merely a reflection of current misunderstanding.⁷⁷ In other words, Pollard and all who make a similar case for SDA assume that the CI is the only valid interpretation of quantum theory.

Having asserted the reality of quantum indeterminacy, Pollard then goes on to explain that “the appearance of chance and accident in history” is the key to the biblical doctrine of providence.

What Israel perceived as a mighty act of God was to other peoples only a particularly favorable combination of circumstances. What Israel called Providence, the Greek called Fortune. What to the faithful is an act of divine mercy showing forth our Lord’s restorative power is for the pagan merely a piece of extraordinarily good luck.⁷⁸

⁷⁷Ibid., 43.

⁷⁸Ibid., 66.

Even if we grant this, it remains for Pollard to explain how God's tampering with quantum indeterminacy can bring about effects in the macroscopic realm. This is the amplification problem: how can ostensibly lawless quantum phenomena make a mark on a supra-atomic reality that is governed impressively by natural law? The best Pollard can do is cite the possibility that gene mutation, which can be brought about by factors falling under the influence of quantum physics, can produce macroscopic effects. Beyond this, all he can say is that wherever else science manifests variability and probability we "must suppose that they arise out of as yet undefined principles or sources of indeterminacy proper to biological organisms or man as such."⁷⁹ Steven Crain summarizes Pollard's argument nicely.

[Pollard] insists that the empirical success of quantum mechanics, coupled with the failure of classical physics to cope with a vast range of macroscopic phenomena like turbulence, implies that quantum mechanics should replace classical physics as the paradigm according to which the pervasive use of statistical explanation in macroscopic sciences should be understood. This means that just as the Heisenberg indeterminacy principle reveals that quantum processes are indeterministic, thus accounting for the statistical character of quantum mechanics, so too analogous 'indeterminacy' principles must operate at macroscopic levels, accounting for the statistical character of sciences like biology and psychology.⁸⁰

Philip Clayton joins Pollard in arguing that quantum indeterminism makes SDA scientifically feasible. In fact, he begins by stressing that the task of the theologian is not to *prove* SDA, but rather to show that such a thing is *possible* in light of what we know about the world.⁸¹ Clayton thinks the possibilities are promising, for, as he says, the widely accepted CI "argues for an actual *ontological indeterminacy*," which means theologians can posit quantum-based SDA without fear of effacing the integrity of science or making theology vulnerable to embarrassing future developments in science.⁸² Clayton's

⁷⁹Ibid., 56.

⁸⁰Steven Dale Crain, "Divine Action and Indeterminism: On Models of Divine Agency that Exploit the New Physics" (Ph.D. diss., University of Notre Dame, 1993), 47-48.

⁸¹Philip D. Clayton, *God and Contemporary Science* (Edinburgh: Edinburgh University Press, 1997), 193.

⁸²Ibid., 193-94.

argument effectively takes the following form: the CI is the established and true interpretation of quantum physics and will not be overturned, and therefore quantum indeterminacy is most assuredly a true fact of science and can safely be used in constructive theology. As for the amplification problem, Clayton essentially dodges it by saying that billions upon billions of divine interventions in the quantum realm *might* result in the macroscopic effects necessary to secure SDA.⁸³ It is hard to escape the impression that Clayton is *hoping* rather than *arguing* here. Finally, Clayton thinks the quantum mechanical case for SDA can at one and the same time demonstrate the possibility of SDA and yet shield specific instances of SDA from scientific identification and subsequent scrutiny. Clayton describes why this is important to theologians:

This fact is important because thinkers have worried in the past that, if a particular locus for God's actions were specified, humanity would then possess a proof of God's existence and action. It would follow, they worried, from a pattern of divine guidance emerging unambiguously *within the discipline of physics itself*, that the role of religious faith would disappear and 'God' would become merely a component of natural science itself – certainly a *reduction ad absurdum* of natural theology!⁸⁴

Thomas Tracy says we should expect that the world has a “gappy” structure if God really acts in history.⁸⁵ Not surprisingly, Tracy identifies the gaps by an appeal to quantum acausality, and then preserves them against possible future elimination by siding with the CI against the possibility that hidden variables capable of recovering causality in quantum physics will someday be discovered.⁸⁶ Hence, indeterminism is here to stay. With Clayton, Tracy emphasizes that this model for SDA preserves the secrecy of God's actions. He also points out that God can act at the quantum level without acting as a

⁸³Ibid., 194.

⁸⁴Ibid. G. P. Thompson similarly says God's actions in such a model cannot be traced by experiment. See Mervyn Stockwood, *Religion and the Scientists: Addresses Delivered in the University Church, Cambridge* (London: SCM Press, 1959), 53-54.

⁸⁵Thomas F. Tracy, “Particular Providence and the God of the Gaps,” in *Chaos and Complexity: Scientific Perspectives on Divine Action*, ed. Robert John Russell, Nancey Murphy, and Arthur Peacocke (Vatican City: Vatican Observatory Publications, 1995), 310.

⁸⁶Ibid., 314-15.

“quasi-physical force, manipulating sub-atomic ‘particles’ as though they were determinate entities.” Rather, God can bring about, apparently by apprehension similar to the observer-dependence doctrine in the CI, any one of the nearly infinite number of potentialities inherent in any given quantum system.⁸⁷

Whereas Pollard argues for divine determination of every quantum indeterminism, Tracy makes a case for a much more limited variety of divine action because he fears exhaustive determinism models in quantum-based arguments for SDA will raise the specter of unmitigated divine determinism at every level of reality.⁸⁸

Finally, Tracy notes two problems that beset the otherwise promising appeal to quantum mechanics. First, there is the amplification problem. While he suggests that quantum events trigger chaotic systems operating on the macro-level, which in turn amplify the quantum effects, thus “elaborating at the macroscopic level the consequences of indeterministic chance at the smallest scales,” the fact is he feels compelled to admit that the science of his explanation “remains uncertain.”⁸⁹ It is certainly that. Second, Tracy points out a problem related to the first point, namely, the problematic ontology of quantum theory. Quantum theory simply does not come with a ready-made, user-friendly metaphysics.⁹⁰ If theologians want to use quantum theory in their theological formulations, they will have to struggle alongside physicists and philosophers to grasp the metaphysical difficulties presented by the subatomic world.

G. F. R. Ellis appeals to quantum indeterminacy to argue that divine revelation is possible without violations of natural law. God might, for instance, sustain creation in such a way as to determine the factors leading to the collapse of wave functions operative

⁸⁷Ibid., 318-19.

⁸⁸Ibid., 320.

⁸⁹Thomas F. Tracy, “Evolution, Divine Action, and the Problem of Evil,” in *Evolutionary and Molecular Biology: Scientific Perspectives on Divine Providence*, ed. Robert John Russell, William R. Stoeger, and Francisco J. Ayala (Vatican City: Vatican Observatory Publications, 1998), 515.

⁹⁰Tracy, “Particular Providence,” 314-15.

in a particular human brain. Hence, revelation is not miraculous, but rather an operation of the natural order as directed by God.

One can thus envisage the creator providing images as desired to individuals, or stimulating specific memories already existent by controlling the specific energy exchanges between particular excited states in the brain, without violating quantum mechanics in any way. If there are very few such events needed to provide a particular image, they will have a negligible effect on the overall statistics; if there were many, compensating exchanges would have to be arranged to keep the statistics within reasonable bounds, which is presumably possible.⁹¹

Ellis grants that many physicists and philosophers will find this proposal objectionable, but since it comports with “the foundations of modern physics” they will be unable to disprove it.⁹² Again, the fact that the CI reigns over quantum theory allows Ellis to presume the ontological reality of quantum acausality.

Nancey Murphy believes the prevailing presumption of indeterminacy on the quantum level provides a “valuable ingredient” for SDA.⁹³ She begins her case by considering four possible conclusions about causality and randomness in quantum events. First, quantum events may be undetermined in the very strictest sense of the term, such that there is no cause of quantum outcomes. Second, the events may be determined by factors (e.g. hidden variables) internal to the quantum system. Third, they may be determined externally, by causal factors related to the system. Fourth, the events may be determined by God.⁹⁴ She chooses this last possibility. The CI comes into play in the following manner: Murphy proceeds on the orthodox interpretation’s assumption that there are no physical hidden variables operative in quantum systems. Hence, quantum systems are causally unconditioned from the natural, physical standpoint. Murphy illustrates the

⁹¹G. F. R. Ellis, “The Theology of the Anthropic Principle,” in *Quantum Cosmology and the Laws of Nature: Scientific Perspectives on Divine Action*, 2nd ed., ed. Robert John Russell, Nancey Murphy, and C. J. Isham (Vatican City: Vatican Observatory Publications, 1996), 391.

⁹²*Ibid.*, 392.

⁹³Nancey Murphy, “Divine Action in the Natural Order: Buridan’s Ass and Schrödinger’s Cat,” in *Chaos and Complexity: Scientific Perspectives on Divine Action*, ed. Robert John Russell, Nancey Murphy, and Arthur Peacocke (Vatican City: Vatican Observatory Publications, 1995), 354.

⁹⁴*Ibid.*, 341.

implications of this indeterminism by appeal to medieval Parisian philosopher Jean Buridan's story about a hungry donkey.

[Buridan hypothesized that] if a starving donkey were placed midway between two equal piles of hay it would starve to death for want of sufficient reason to choose one pile rather than the other. I am supposing that entities at the quantum level are miniature 'Buridian' asses. The asses have the 'power' to do one thing rather than another (walk to one of the piles of hay). The question is what induces them to take one course of action rather than the other (or to take a course of action at a particular time rather than another or not at all). By hypothesis, there is nothing external to determine the donkey's choice (no difference in the piles of hay). Also, by hypothesis, there is nothing internal (no sufficient reason) to determine the choice.⁹⁵

Like the starved but indecisive donkey, quantum entities would forever stall between options if left to their own devices. Having adopted the Copenhagen position on the impossibility of natural hidden variables, Murphy opts to name God as the immaterial, *supernatural* hidden variable, who alone "causes" random quantum events to decide between variant options.⁹⁶

Robert John Russell also takes quantum physics to signal indeterminism in micro-reality, and combines this with molecular and evolutionary biology to assert that God works through the evolutionary process to "achieve biological consequences through 'bottom-up' causality," all without violating natural law.⁹⁷

If it can be shown scientifically that quantum mechanics plays a role in genetic mutations, then by extension it can be claimed theologically that God's action in genetic mutations is a form of objectively special, non-interventionist divine action. Moreover, that God's action plays a key role in biological evolution, and our hypothesis is warranted.⁹⁸

Russell considers and rejects the possibility that his model for SDA rests on "epistemic gaps" in science. He claims instead that ontological indeterminism is a *known*

⁹⁵Ibid.

⁹⁶Ibid., 342.

⁹⁷Robert John Russell, "Religion and the Theories of Science: A Response to Barbour," *Zygon* 31 (1999): 38.

⁹⁸Robert John Russell, "Special Providence and Genetic Mutation: A New Defense of Theistic Evolution," in *Evolutionary and Molecular Biology: Scientific Perspectives on Divine Action*, ed. Robert John Russell, William R. Stoeger, and Francisco J. Ayala (Vatican City: Vatican Observatory Publications, 1998), 206.

fact of quantum science.⁹⁹ Clearly he sides with the CI against natural causation and hidden variables.

Ian Barbour makes a case similar to Russell's. While he grants that quantum indeterminacy, which he too takes to be an ontological reality, is "averaged over" for everyday objects, he argues that biological entities such as nervous systems and genetic material may directly manifest the effects of quantum outcomes.¹⁰⁰ If these effects are selected for propagation in the evolutionary process, we have the coincidence of evolutionary chance and divine providence.

Like Tracy above, Barbour thinks it is important to note that this model of SDA does not require God to do anything unordinary to bring about specific quantum outcomes. All quantum potentialities have the same energy value, so a quantum system can choose equally between options without requiring energy input. Hence, God can "cause" without inputting energy.¹⁰¹ This is SDA by stealth, and it preserves the integrity of the natural order and protects God from the problem of evil because, as Barbour argues, God only determines *some* quantum events rather than all of them.¹⁰²

Finally, E. L. Mascall suggests God may be the cause of quantum events, but more so than those surveyed above he wishes to caution against heavy reliance on quantum-based models for SDA. About the most that can be said, he suggests, is that current physical theory is "somewhat more congenial" to Christian doctrines than that which it replaces.¹⁰³

Assessing the case for quantum-based SDA. Arguments for SDA predicated

⁹⁹Ibid., 216.

¹⁰⁰Ian Barbour, *Nature, Human Nature, and God* (Minneapolis: Fortress Press, 2002), 19.

¹⁰¹Ibid., 27.

¹⁰²Ibid., 28. Also see Barbour, *When Science Meets Religion* (San Francisco: Harper & Row, 2000), 87.

¹⁰³E. L. Mascall, *Christian Theology and Natural Science: Some Questions in Their Relations* (New York: Longmans, Green, and Company, 1956), 202.

on quantum indeterminacy are problematic for several reasons. First, there is the aforementioned amplification problem. Jeffrey Koperski concludes that even if God does determine the outcomes of otherwise indeterminate quantum events, He would be unable to bring about significant macroscopic effects by this fact.¹⁰⁴ Similarly, Peter Hodgson says quantum indeterminacy does not purchase indeterminacy in the macro world, and therefore does not provide an avenue for SDA.¹⁰⁵ He also notes that the CI is “positivistic obscurity,” a point with which I agree and name as a second major difficulty with quantum-based models for SDA.¹⁰⁶ Keith Ward comes to a similar conclusion, saying quantum theory is too controversial to ground properly the account for divine action.¹⁰⁷

Nicholas Saunders summarizes several problems with quantum SDA models in the following paragraph.

The scale of the providence required for divine action through quantum physics is truly phenomenal: it takes millions of years of action to achieve even the most simple effects. If it is also held that human beings have free will, then this situation becomes absurd. By making quantum measurements we are determining the state of divine determinations in a way that must significantly increase the already considerable amount of time God requires to achieve anything. The linking of divine action to quantum mechanics must take place by some kind of measurement interaction, and this also places God in a subordinate position to creation, and the episodic nature of measurements places severe limitations on the possible actions God could achieve. . . . It seems reasonable to conclude that a theology of divine action that is linked to quantum processes is theologically and scientifically untenable.¹⁰⁸

Finally, Hodgson rightly notes that the attempt to explain SDA via quantum indeterminacy is the mark of an impoverished theological conception. God is the supreme Lord of creation, he says, and as such it is unwarranted to suppose that God must work

¹⁰⁴Jeffrey Koperski, “God, Chaos, and the Quantum Dice,” *Zygon* 35 (2000): 546.

¹⁰⁵Peter E. Hodgson, “God’s Action in the World: The Relevance of Quantum Mechanics,” *Zygon* 35 (2000): 514.

¹⁰⁶*Ibid.*, 511.

¹⁰⁷Keith Ward, “Divine Action in the World of Physics: Response to Nicholas Saunders,” *Zygon* 35 (2000): 901.

¹⁰⁸Nicholas T. Saunders, “Does God Cheat at Dice? Divine Action and Quantum Possibilities,” *Zygon* 35 (2000): 541-42.

within the confines of laws or indeterminacies to pull off his desired ends.¹⁰⁹ With this I heartily agree. In fact, as I will indicate in the conclusion to this study, natural law *cannot* conscribe God's actions because in fact natural law is nothing other than an imperfect scientific description of God's habits of providence. The law of causality does not stand outside God as a force with which he must reckon. Rather, the law describes the work of God in creation. Hence, any apologetic for SDA that begins by searching for genuine indeterminism in the natural order has gotten off on the wrong assumption, namely, that causal determinism is a threat to God's ability to act in the world.

Miscellaneous Theological Issues

Can God know or do all things if quantum events are truly indeterminate? Arthur Peacocke thinks not, and makes his case by appeal to two suppositions: first, that God has made quantum indeterminacy a fact of our world so that he may purposefully limit himself in order to achieve his purposes for humanity, and second, that the future has no ontological status.¹¹⁰ Peacocke favors a process view over more traditional concepts of divine action, and so he has little interest in arguing that God determines quantum events in order to direct history. This creates some separation between Peacocke and those cited above, but nevertheless he shares with them a fundamental reliance on the terms of the CI, for his denial of divine omniscience and omnipotence rests partly on the presumption that quantum indeterminacy will not be revoked by the future discovery of hidden variables.¹¹¹

Godwin Fernando takes the CI to imply that Christian metaphysics must be reworked along interdisciplinary lines in order to incorporate the entailments of quantum physics. He proposes a new discipline, which he calls zygology, which synthesizes theol-

¹⁰⁹Hodgson, "God's Action," 514.

¹¹⁰Peacocke, "God's Interaction," 280, and idem, *Theology for a Scientific Age: Being and Becoming – Natural, Divine and Human*, 2nd ed. (Minneapolis: Fortress Press, 1993), 121.

¹¹¹Peacocke, "God's Interaction," 281.

ogy, quantum physics, cosmology, metaphysics, and philosophy.¹¹² The most notable outcome of Fernando's zygology is the conclusion that, in keeping with certain Copenhagen theorists, human acts of observation created the universe.

William H. Austin has proposed that the Copenhagen doctrine of complementarity, based on wave-particle duality, might be useful for solving what he calls the paradoxes of religious discourse. For instance, he suggests that God being both a loving Father and merciful judge is a theological paradox, and that it might be resolved by the appeal to complementarity.¹¹³ Saunders notes that others have called for the metaphorical application of quantum duality concepts to Christological issues such as the Son's dual nature, human and divine.¹¹⁴ D. M. MacKay argues that the complementarity doctrine may help theologians resolve the apparent contradictions that seem to arise when theological and scientific explanations are given for the same event.¹¹⁵ As examples, he cites conversion to Christ, which he believes can be explained genuinely and exhaustively by both psychological and spiritual factors, and the foodstuffs that sustain birds, the provision of which can be described both theologically and naturally.¹¹⁶ Dana Edgar Bible likes MacKay's approach and adopts a hierarchical ontology incorporating the complementarity doctrine in the following way. "Complementarity serves as a useful means of communicating meaning between hierarchical levels. Meaning at one level does not determine meaning for all other levels. When discussing the same reality from different hierarchical perspectives the various descriptions are considered to be complementary descriptions."¹¹⁷

¹¹²Godwin Fernando, *Christian Metaphysics and Quantum Physics: A Theology – Physics Interface* (Ratmalana, Sri Lanka: Vishva Lekha Publishers, 2003), 258-59.

¹¹³William H. Austin, "Complementarity and Theological Paradox," *Zygon* 2 (1967): 366, 379.

¹¹⁴Nicholas T. Saunders, *Divine Action and Modern Science* (Cambridge: Cambridge University Press, 2002), 95.

¹¹⁵D. M. MacKay, "Complementarity in Scientific and Theological Thinking," *Zygon* 9 (1974): 229-32.

¹¹⁶*Ibid.*, 238-39.

¹¹⁷Bible, "Metaphysical Implications," 178. On Bible's adoption of the hierarchical ontology,

In response to such employments of the complementarity doctrine, James Park concludes that theologians who engage quantum mechanics display “a basically commendable interdisciplinary spirit,” but that they simply tend to misuse the physics.¹¹⁸ This is an important point, but more important still are the following. First, the legitimacy of the doctrine of complementarity stands or falls with the CI, which is the subject of ongoing contention in both physics and philosophy. If the CI is someday overturned, whatever has been built atop it will be weakened or overthrown depending on the extent of its dependence on the failed interpretation. Second, it seems clear that the appeal to complementarity to solve theological paradoxes is both superfluous and logically fallacious. In the first place, it is superfluous because acceptable theological and philosophical options are at hand, as for instance the distinction between primary and secondary causation as a means of explaining how historical and natural events can be at once the work of both God and humans. In the second place, the appeal to complementarity is logically fallacious because there is no correspondence between, say, the dual nature of Christ and the duality the CI posits for quantum entities. The complementarity doctrine arises due to difficulties in the measurement of physical micro-reality. Are Christ’s natures physical? Does His human nature have point-like position? Does His divinity have momentum or amplitude? Certainly not. Therefore, attempts to interpret theological categories along quantum-physical lines seem insensible.

Chapter Summary

Though the CI may initially seem to be a handy proof for various holistic, Eastern mystical, and even Christian convictions, the fact is that it fails to secure unquestioned credibility for any of these viewpoints. Real-world entanglement is not nearly so pervasive as to warrant quantum-based universal holism. Claims that the quantum parti-

ibid., 171-72.

¹¹⁸James L. Park, “Complementarity Without Paradox: A Physicist’s Reply to Professor Austin,” *Zygon* 2 (1967): 382.

cles that compose our bodies are entangled with every other particle in the universe dating back to the Big Bang grossly overstep the actual facts of entanglement. Nevertheless, in keeping with the spirit of the CI, some interpreters are content to push quantum holism as one of several indicators that the world is vastly different from traditional Western conceptions have suggested.

The CI comes closer to fitting core elements of the Eastern outlook than any other worldview. As Ricard noted above, Bohr's writings contained strong elements of Eastern thought. The doctrine of complementarity in particular seems to benefit Buddhist doctrines. However, it seems doubtful that a sustained apologetic for the Eastern worldview can be built atop quantum mechanics, for as Stenger noted above, Eastern apologists have thus far tended to root through quantum science in search of commonalities while neglecting to handle problematic issues.

As for the CI as a proof for either human or divine freedom, the case is to be rejected due mainly to the inability of genuine indeterminacy to secure rational freedom, the amplification problem, the false presumption that the Christian worldview demands the presence of physical indeterminism to secure human and divine freedom, and the theology-of-the-gaps problem that will surface in the likely event that the CI is set aside for a more rational view of quantum science.

CHAPTER 5

CRITICAL ANALYSIS OF THE COPENHAGEN INTERPRETATION

As we have seen in the previous two chapters, the presumption that the Copenhagen interpretation is the only viable interpretive option for quantum physics leads to all sorts of worldview applications. In this chapter, which constitutes my proposal, I will argue that the CI is not inviolable. In fact, the orthodox interpretation is inextricably bound up with philosophical predispositions that run counter to historic underpinnings for science and historic expressions of the Christian worldview. On these counts and others, I argue that we should deny to the CI the privileged position it has held for eighty years.

The Copenhagen Cohort

Uncovering the philosophical lattice that holds up a scientific theory is important but often-difficult work. It is important because each researcher's worldview significantly determines what expectations he formulates as he designs the experiment and formulates his hypothesis. Furthermore, his worldview will shape his judgment of the empirical returns. Here, philosophical preconditions play a large role in shaping scientific theory.

For historians and philosophers of science, however, discerning the nature of these preconditions is not always a simple matter, for in some sense it is the nature of the scientific task to leave such factors unmentioned. Max Jammer notes this fact, and therefore suggests that philosophers must consult the scientist's biographies, personal correspondence, and autobiographical remarks in order to unearth the significant role

philosophy has played in scientific formulations.¹

Jammer's recommendation becomes all the more important in cases where a small handful of like-minded scientists have teamed together to shape an entire field, as is the case with quantum theory. Moreover, as Mara Beller notes, the philosophical predispositions of the founders of quantum theory are especially important in light of the fact that the genuinely scientific portion of the theory (the mathematical formalism) does not condition interpretive options.

The neutrality of a mathematical formalism with respect to possible interpretations has another far-reaching consequence: scientists may give all authority in interpretive matters to a few leaders, whose philosophy they are willing to accept. Such humble resignation from philosophical exploration is often nothing but a convenient choice not to deal with confusing and perhaps irrelevant matters. It is this attitude that creates room for an authoritative and privileged interpretation, such as the Copenhagen orthodoxy.²

In the following pages, I will examine important philosophical and character traits of the three men who are chiefly responsible for the orthodox interpretation of quantum physics. These men, the Copenhagen Cohort as I call them, are Niels Bohr, Wolfgang Pauli, and Werner Heisenberg. The lion's share of attention goes to Bohr, for clearly he is the fountainhead of vision and charisma that filled the physics world with the Copenhagen spirit.

Niels Bohr

Bohr the communicator. Niels Bohr was a physicist of privilege. In a time when monies and other resources were short for physicists around the globe, Bohr headed up a well-equipped laboratory in Copenhagen, Denmark. Rather than bar the door to lesser-privileged physicists, Bohr shared his facilities and his time very generously. A

¹Max Jammer, *The Conceptual Development of Quantum Mechanics*, 2nd ed, vol 12 of *The History of Modern Physics, 1800-1950*, ed Gerald Holton and Katherine R. Sopka (United States of America: Tomash Publishers, 1989), 174.

²Mara Beller, *Quantum Dialogue: The Making of a Revolution* (Chicago: University of Chicago Press, 1999), 4.

steady stream of gifted young physicists came from literally all around the world to work with Bohr. As Victor Weisskopf describes it, Bohr was masterful at drawing the best out of his young beneficiaries. “We see him, the greatest among his colleagues, acting, talking, living as an equal in a group of young, optimistic, jocular enthusiastic people, approaching the deepest riddles of nature with a spirit of attack, a spirit of freedom from conventional bonds and a spirit of joy that can hardly be described.”³

To keep their spirits high, Bohr periodically forced his young protégés to evacuate the laboratory and pursue some of the recreational activities that were typical for men their age. These included cowboy movies, girl-watching, ping-pong, and jokes made at Bohr’s expense.⁴ When the merriment ended, however, it was back to work, where Bohr himself set a relentless pace. Jeremy Bernstein says Bohr’s role at the institute was Socratic, and indeed it was, but Bohr displayed a tenacity that better fit a field commander than a mere teacher of philosophy. Bernstein relays an account in which Erwin Schrödinger, a brilliant physicist who found it difficult to accept Bohr’s interpretation of quantum physics, felt compelled to retreat to his dormitory room to escape Bohr’s persistence. It was no use, for Bohr followed the bedraggled Schrödinger all the way to his closed door to continue the dispute.⁵

Schrödinger would forgive Bohr for such behavior, and Bohr was universally regarded as a congenial man. In one important sense Bohr needed to be liked by his fellow physicists. The reason is simple but surprising: Bohr was rather poor at mathematics, at least so far as theoretical physicists go. Beller cites the surprise one physicist felt upon learning this about Bohr.

When John Slater came to work with the great Bohr in Copenhagen, he discovered, to his amazement, that Bohr had no use for mathematics: ‘I had supposed, when I

³Victor F. Weisskopf, “Niels Bohr, the Quantum, and the World,” *Physics Today* 38 (October 1985): 192.

⁴William H. Cropper, *The Quantum Physicists: And an Introduction to Their Physics* (Oxford: Oxford University Press, 1970), 36.

⁵Jeremy Bernstein, *Cranks, Quarks, and the Cosmos* (New York: Basic Books, 1993), 43.

went to Copenhagen, that although Bohr's papers looked like hand-waving, they were just covering up all the mathematics and careful thought that had gone on underneath. The thing I convinced myself of after a month was that there was nothing underneath.⁶

For this and other reasons Bohr gathered to himself bright minds from all over the world, pooled their collective genius, and then “guided, restrained, deepened, and finally transmuted” their efforts into expression of what would come to be known as the Copenhagen interpretation of quantum mechanics.⁷ As the CI was coming to maturation, it was spread quickly among theoretical physicists largely because their community was small and the lines of communication through conferences and journals were very effective.⁸ What was spreading via these avenues was not just Bohr's take on quantum theory, but his take on larger philosophical issues.

The connection between Bohr's work and the whole of his personality is so close that one can almost speak of an identity. The turn he gave to the trend of modern physics and through which it received its far reaching epistemological consequences, arose so directly from and harmonized in such a rare degree in his own mind, that one dares to use of him the phrase which one would otherwise reserve for the great artists: that he created a world from within.⁹

David Lindley calls Bohr the father figure of the CI, and says his writings are of talmudic importance and are consulted to this very day when difficult questions arise in quantum physics.¹⁰ The allusion to the Talmud is particularly appropriate in Bohr's case, for indeed he came to be something of a religious figure among his contemporaries.

⁶Beller, *Quantum Dialogue*, 259.

⁷Cropper, *Quantum Physicists*, 36.

⁸Alan A. Grometstein, *The Roots of Things: Topics in Quantum Mechanics* (Boston: Kluwer Academic, 1999), 408.

⁹Jorgen Kalckar, “Niels Bohr and His Youngest Disciples,” in *Niels Bohr: His Life and Work as Seen by His Friends and Colleagues*, ed. Stefan Rozental (New York: North-Holland, 1985), 229.

¹⁰David Lindley, *Where Does the Weirdness Go? Why Quantum Mechanics is Strange, but Not as Strange as You Think* (New York: BasicBooks, 1996), 105. Paul Feyerabend expresses something of a contrary view with reference specifically to Bohr's reception among his contemporaries. Feyerabend insists that Bohr did not win the physics world over to the CI by virtue of his being universally-liked by his fellows. In fact, says Feyerabend, Bohr was surrounded by a group of illuminati who were “aggressive and disrespectful” toward him. Paul Feyerabend, *Farewell to Reason* (New York: Verso, 1987), 185. Feyerabend is quite out of step with the host of commentators who have expressed opinions on Bohr's reception among his contemporaries.

John Heilbron says a dig through Bohr's correspondence reveals that many people regarded him "not only as teacher of physics but also as guide to life."¹¹ Strangely, Bohr may have been quite pleased with this. After all, he came to believe his doctrine of complementarity could become a veritable guide to life. Léon Rosenfeld once mused with Bohr about people's motives for adopting religion. It is because they cannot get guidance and consolation from science, Rosenfeld asserted. To this Bohr responded by intensely expressing his expectation that the complementarity doctrine would someday be taught as a matter of fact in general education, and that it would serve the needs of humanity better than religion.¹²

Freeman Dyson says contemporary inheritors of Bohr's tradition have corrupted his thought, much like disciples of religious leaders and philosophers have done throughout history, and that the CI has therefore become something Bohr never intended it to be.¹³ No doubt there is some truth to this, especially in cases where the CI is used to legitimate extreme postulations made by New Agers such as Fritjof Capra. Nevertheless, even if Bohr would not endorse all the religious and quasi-religious ends to which his CI has been applied, the fact remains that Bohr himself clearly wrote religious and philosophical tones into his philosophy of physics with statements such as he made to Rosenfeld above.

Bohr's central importance in quantum physics is complicated by the fact that he was not a gifted communicator of complex concepts. Bohr himself was very conscious of this. For instance, he once confessed that he was "deeply aware" that the "trend of the argumentation" in his response to the EPR paper was difficult to understand.¹⁴ No doubt

¹¹John Heilbron, "The Earliest Missionaries of the Copenhagen Spirit," in *Science in Reflection*, vol. 3 of *The Israel Colloquium: Studies in History, Philosophy, and Sociology of Science*, ed. Edna Ullmann-Margalit (Boston: Kluwer Academic, 1988), 221.

¹²Ibid.

¹³Freeman J. Dyson, "Thought-experiments in Honor of John Archibald Wheeler," in *Science and Ultimate Reality: Quantum Theory, Cosmology, and Complexity*, ed. John D. Barrow, Paul C. W. Davies, and Charles L. Harper (Cambridge: Cambridge University Press, 2004), 76.

¹⁴Niels Bohr, "Discussions with Einstein," in *Quantum Theory and Measurement*, ed. John

this troubled Bohr, but he learned to take it in stride and even formulated a standard quip he offered to anyone who had difficulty understanding him: “You didn’t understand? That’s too bad. I never expressed myself so clearly before.”¹⁵

Bohr traveled extensively, spreading the word about the CI in many different academic venues. America was an especially favorite destination for him, and Americans seemed glad of it. He was received warmly here, but it is doubtful many people understood him, for added to his general deficiencies as a communicator are the facts that his English was anything but polished and his speech came out as a slow “interminable, multiclause, self-denying, involuted” stream of confusion, due in part to his well-founded fear of miscommunication.¹⁶ Ironically, difficulties such as these seem to have helped catapult Bohr’s philosophy into stratospheric popularity. “It seems that the more one feels at a loss to extract a clear and coherent message from Bohr’s philosophy, the more often one calls it ‘subtle’ and ‘ingenious.’ This terminology creates a qualitative gap between oneself and the hero, excusing inability to understand and simultaneously preventing criticism of the hero’s authority.”¹⁷

A final factor contributing to the difficulty of deciphering Bohr is the fact that

Archibald Wheeler and Wojciech Hubert Zurek (Princeton: Princeton University Press, 1983), 42. John Bell, possibly the most gifted physicist since Einstein and Bohr, once said he had “very little idea” what Bohr was saying in an important argument against Einstein. John Bell, “Bertlmann’s Socks and the Nature of Reality,” in *Speakable and Unsayable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 155.

¹⁵Paul Feyerabend, *Killing Time: The Autobiography of Paul Feyerabend* (Chicago: University of Chicago Press, 1995), 78. Bohr was also fond of telling an apparently self-referential anecdote about a rabbi who delivered a series of brilliant addresses. “The rabbi spoke three times. The first talk was brilliant; clear and simple. I understood every word. The second was even better; deep and subtle. I didn’t understand much, but the rabbi understood all of it. The third was by far the finest; a great and unforgettable experience. I understood nothing, and the rabbi didn’t understand much either.” Cited in Henry J. Folse, *The Philosophy of Niels Bohr: The Framework of Complementarity* (Amsterdam: North-Holland Physics Publishing, 1985), 258.

¹⁶Grometstein, *Roots*, 441. Amir D. Aczel says Bohr tried to improve his English by reading Charles Dickens, but that he was forced to consult the dictionary for every other word. See Amir D. Aczel, *Entanglement: The Greatest Mystery in Physics* (New York: Four Walls Eight Windows, 2002), 40. John Honner says Bohr was forever casting about for the right words and still had trouble communicating with others. John Honner, *The Description of Nature: Niels Bohr and the Philosophy of Quantum Physics* (Oxford: Clarendon Press, 1987), 220.

¹⁷Beller, *Quantum Dialogue*, 272.

he really does not offer a consistent, comprehensive framework for interpreting quantum physics. Abner Shimony confesses that after twenty-five years of careful, even “re-
 verent” searching of Bohr’s writings he has not found such a framework.¹⁸ Beller says a
 consistent framework cannot be found in Bohr because Bohr is genuinely inconsistent.
 She is bewildered by the number of outright contradictions on Bohr’s writings, and notes
 that she is not alone in this assessment.¹⁹

Bohr’s philosophy. Bohr was something of a polymath. As a young man he
 became deeply interested in philosophy and even aspired to write a treatise on epistemol-
 ogy. Specifically, he wanted to explore the interrelations between all fields of knowledge,
 but the glory of physics lured him away from this task for some time. Ironically, as Ruth
 Moore says, quantum physics brought Bohr full circle. By entering physics instead of
 philosophy, Bohr was able to return to philosophy with powerful new conceptual tools
 for describing the interrelationship between all ways of knowing.²⁰

However, Bohr brought more than bare physics to his later philosophical for-
 mulations of quantum theory. For instance, Arkady Plotnitski says Bohr’s doctrine of
 complementarity actually reflects Bohr’s early philosophical positions, positions that
 were formed in dialogue with the works of Kant, Hegel, Kierkegaard, William James,
 Harald Høffding, Nietzsche, and Freud.²¹ Importantly, Bohr’s closest collaborator in
 physics, Werner Heisenberg, once recalled a sailing trip on which Bohr and a handful of
 close associates discussed Bohr’s complementarity doctrine. When Bohr began waxing
 on about how *recent* developments in quantum physics highlighted the limitations of hu-

¹⁸Abner Shimony, review of *The Philosophy of Niels Bohr: The Framework of Complementarity*, by Henry J. Folse, *Physics Today* 39 (October 1985): 109.

¹⁹Beller, *Quantum Dialogue*, 275.

²⁰Ruth Moore, *Niels Bohr: The Man, His Science, & the World They Changed* (New York: Knopf, 1966), 406-07.

²¹Arkady Plotnitski, *Complementarity: Anti-Epistemology after Bohr and Derrida* (Durham, NC: Duke University Press, 1994), 76.

man language and concepts, one of his friends responded by pointing out that Bohr had made the exact same philosophical points many years before his development of the complementarity concept in quantum physics.²² Similarly, Bohr's close associate Wolfgang Pauli congratulated him in 1929, in the early wake of Bohr's revolutionary pronouncements on complementarity and other quantum mechanical issues, on the fact that Bohr had successfully "omitted all physics" and concentrated solely on philosophy!²³ Bohr himself would not deny such claims. His first few drafts of the Como lectures he delivered in 1927 were entitled "The Philosophical Foundations of the Quantum Theory."²⁴ In a letter to C. G. Darwin, Charles Darwin's physicist grandson, Bohr worried over how physicists would receive his non-traditional views, and emphasized that he was hard at the task of tracing the philosophical aspects of quantum theory.²⁵ In fact, virtually everything Bohr ever did in physics was an effort to trace out the philosophical implications. Just before his death, Bohr was asked what role philosophy had played in his early life. He responded by saying, "It was, in a way, my life!"²⁶ The evidence suggests that this remained true of Bohr throughout his life and work in physics, and the Danish Society for Philosophy and Psychology recognized as much by inducting him into their order as an honorary member in 1951.²⁷

I believe Bohr's philosophical interests drove his interpretive efforts in quantum physics. To help establish the likelihood of this claim, it is necessary to look in par-

²²Werner Heisenberg, "Commentary of Heisenberg," in *Quantum Theory and Measurement*, ed. John Archibald Wheeler and Wojciech Hubert Zurek (Princeton: Princeton University Press, 1983), 86; Aage Petersen, "The Philosophy of Niels Bohr," in *Niels Bohr: A Centenary Volume*, ed. A. P. French and P. J. Kennedy (Cambridge, MA: Harvard University Press, 1985), 299.

²³Honner, *The Description*, 72.

²⁴Abraham Pais, *Niels Bohr's Times, In Physics, Philosophy, and Polity* (Oxford: Clarendon Press, 1991), 311-12. Oddly, though Pais acknowledges that Bohr was "one of the major twentieth century philosophers," he nevertheless denies that philosophers influenced Bohr's development of the complementarity doctrine. *Ibid.*, 420-24.

²⁵Honner, *The Description*, 71.

²⁶Petersen, "The Philosophy," 200.

²⁷Pais, *Niels Bohr's Times*, 421.

ticular at the influence Høffding and James had on Bohr, and also to note how closely Bohr reflects certain elements in Kant and Kierkegaard.

Harald Høffding and Christian Bohr, Niels's father, were close friends and colleagues at the University of Copenhagen, where Høffding taught philosophy and Bohr taught biology. In this connection, Høffding was a regular visitor to the Bohr home when Niels was growing up, and by all accounts the young Niels was fond of listening in as Høffding, the elder Bohr, and other intellectual guests traded outlooks on deep issues in science, philosophy, and a host of other stimulating topics. As for Høffding, he returned time and again to the same central themes. For one, he emphasized the widespread psychological fragmentation that marked society at the dawn of the twentieth century and laid blame at the feet of industrialization and mechanistic conceptions of nature.²⁸ He also believed that the major problems in philosophy—which he named as consciousness, knowledge, Being, and values—came down to one problem: the relationship between continuity and discontinuity, which he believed formed an antinomy.²⁹ Høffding therefore took a dialectical outlook on philosophy. Bohr listened carefully to Høffding's expression of the dialectic, and later in life observed that quantum physics had supplied clear, analyzable evidence for dialectical aspects of nature, which fact puts modern man in a more fortuitous position than thinkers of previous generations who lacked scientific evidence for a fundamentally dialectical nature.³⁰

A final component of Høffding's philosophical set that has significant bearing on Bohr's philosophy of quantum mechanics is described by Jan Faye as "objective anti-

²⁸M. Norton Wise, "How Do Sums Count? On the Cultural Origins of Statistical Causality," in *Ideas in History*, vol. 1 of *The Probabilistic Revolution*, ed. Lorenz Krüger, Lorraine J. Daston, and Michael Heidelberger (Cambridge, MA: MIT Press, 1987), 406.

²⁹*Ibid.*, 407-08. See also James T. Cushing, "Copenhagen Hegemony: *Need It Be So?*" in *Symposium on the Foundations of Modern Physics 1990: Quantum Theory of Measurement and Related Philosophical Problems*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific, 1991), 91.

³⁰Léon Rosenfeld, "Commentary of Rosenfeld," in *Quantum Theory and Measurement*, ed. John Archibald Wheeler and Wojciech Hubert Zurek (Princeton: Princeton University Press, 1983), 85. See also Stanley Aronowitz, who indicates that the "metascientific principle" of dialectic influenced physics through Bohr, who in turn was influenced by Høffding. Stanley Aronowitz, *Science as Power: Discourse and Ideology in Modern Society* (Minneapolis: University of Minnesota Press, 1988), 251-52.

realism,” which includes *denial* of “both the correspondence theory of truth and a substance/property ontology, which together involve a belief in transcendent truth conditions.”³¹ Faye sets out to discover whether or not Bohr’s philosophy and development of the complementarity doctrine are reflections of Høffding’s variety of anti-realism, and concludes that in fact Bohr is consistent with Høffding’s position.³² M. Norton Wise reaches the same conclusion, saying that Høffding may not have *caused* Bohr’s philosophy, but that Bohr’s philosophy certainly followed Høffding’s form very closely, especially the emphasis on indeterminism.³³ James Cushing believes Bohr was inclined to develop two staples of his quantum interpretation—the doctrine of complementarity and the postulation of a fundamentally discontinuous structure in quantum nature—as a result of Høffding’s influence.³⁴ Beller concludes that Høffding’s emphasis on wholeness informed all of Bohr’s treatments of complementarity, from first to last.³⁵ Finally, Høffding himself considered Bohr’s interpretation of quantum physics to be an outgrowth from his own ideas on philosophy and psychology, ideas which Bohr imbibed as a young boy sitting at Høffding’s feet in the Bohr home.³⁶

Philosopher of science Max Jammer believes William James was also strongly influential in Bohr’s thought.³⁷ No doubt this influence was made possible largely by Høffding’s having introduced James’s work to Bohr at a young age.³⁸ Gerald Holton fol-

³¹Jan Faye, *Niels Bohr: His Heritage and Legacy. An Anti-Realist View of Quantum Mechanics*, vol. 6 of *Science and Philosophy*, ed. Nancy J. Nersessian (Boston: Kluwer Academic Publishers, 1991), 216.

³²*Ibid.*

³³Wise, “How do Sums Count,” 406-09.

³⁴Cushing, “Copenhagen Hegemony,” 93.

³⁵Beller, *Quantum Dialogue*, 253.

³⁶Faye, *Niels Bohr*, 75.

³⁷Jammer, *Conceptual Development*, 182.

³⁸Gerald Holton, “The Roots of Complementarity,” in *Quantum Histories*, vol. 4 of *Science and Society: The History of Modern Physical Science in the Twentieth Century*, ed. Peter Galison, Michael Gordin, and David Kaiser (New York: Routledge, 2001), 276-78.

lows up on this lead and concludes that Bohr's complementarity bears significant resemblance to James's discussions about the complementarity of component parts of the human consciousness. In particular, Holton cites the following passage from James as suggestive that Bohr has adopted an important theme from James.

It must be admitted, therefore, that in *certain persons*, at least, *the total possible consciousness may be split into parts which coexist but mutually ignore each other*, and share the objects of knowledge between them. More remarkable still, they are *complementary*. Give an object to one of the consciousnesses, and by that fact you remove it from the other or others. Barring a certain common fund of information, like the command of language, etc., what the upper self knows the under self is ignorant of, and *vice versa*.³⁹

Bohr seemingly applied this line of thought to his complementarity doctrine, says Holton.⁴⁰ Interestingly, the day before he died, Bohr told Thomas Kuhn that he had read James as early as 1905 and found him to be "most wonderful."⁴¹ In particular, Bohr mentioned a chapter entitled "The Streams of Consciousness," which is from the work Holton cites above. Holton concludes that while the evidence that James directly influenced Bohr is not definitive, it is substantial enough to permit "plausible speculations."⁴²

It seems best to say that the link between Bohr and James is tentative at best. No doubt Høffding's express fondness for James left a mark on Bohr, and of course Bohr himself said he found James helpful, but in the final analysis James's talk of complementary elements in human consciousness and Bohr's emphasis on quantum complementarity may not be substantially linked.

A much stronger case can be made for Bohr's relation to Kant and Kierkegaard, though to my knowledge he never specifically named either of them as philosophical mentors. In fact, K. V. Laurikainen notes that Bohr even billed his epistemology as anti-Kantian because it did not take epistemological limitation to be an a priori given

³⁹William James, *The Principles of Psychology* (New York: Dover Publications, 1950), 1: 206.

⁴⁰Holton, "The Roots," 274-75.

⁴¹*Ibid.*, 272.

⁴²*Ibid.*, 276.

stemming from the strictures of percepts and precepts. Rather, Bohr took the limitation to be an a posteriori fruit of empirical research.⁴³ Nevertheless, Laurikainen concludes that Bohr's position is fundamentally Kantian even though Bohr does not include Kant's categories in his epistemology.⁴⁴ Indeed, it seems necessary to conclude that the core Kantian theme of phenomenal-noumenal distinction composes the whole warp and woof of Bohr's interpretation of quantum mechanics.

On Bohr's account of it, quantum mechanics seems to point towards regions of speculative thought which offer no hold for conceptual understanding or for any explanation that would not give rise to intractable paradoxes and aporias. In the end he is obliged, like Kant, to posit the existence of a noumenal realm, one to which we can never have access by virtue of our dependence on just those 'classical' concepts – of space, time, position, velocity, causal relations, distributive (bivalent) truth-values, and so forth – which constitute the limits of 'natural language' and of any science which at some point is constrained to operate within those limits.⁴⁵

Clifford Hooker explains that, for Bohr, this means we cannot say what the world is like independent of the circumstance of our experimentation. Clearly this is a form of anti-realism.

This is in complete contrast to the classical realist metaphysics and epistemology where the world is conceived as being the way classical theory says it is, independently of our experimental exploration of it, and where experiments form a subset of the theoretically described behavior of that world, a subset which merely reveals information of interest to us. It is this new understanding of the epistemological role of conceptual scheme(s) (the 'description problem') which constitutes Bohr's real 'quantum revolution'. These remarks begin to disclose the full measure of Bohr's Kantianism⁴⁶

Hooker goes on to say Kant's successors were tempted to deny the reality of the "thing-in-itself" because of the epistemological inaccessibility of the noumenal realm,

⁴³K. V. Laurikainen, "Wolfgang Pauli's Conception of Reality," in *Symposium on the Foundations of Modern Physics: The Copenhagen Interpretation 60 years After the Como Lecture*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific Publishing, 1987), 224.

⁴⁴Ibid.

⁴⁵Christopher Norris, *Against Relativism: Philosophy of Science, Deconstruction, and Critical Theory* (Oxford: Blackwell, 1997), 112-13.

⁴⁶Clifford Hooker, "The Nature of Quantum Mechanical Reality: Einstein Versus Bohr," in *Paradigms and Paradoxes: The Philosophical Challenge of the Quantum Domain*, ed. Robert G. Colodny (Pittsburgh: University of Pittsburgh Press, 1972), 156.

and that Bohr falls into this very temptation.⁴⁷

Kierkegaard was another pivotal philosopher for Bohr's formulation of quantum philosophy. Jammer finds reference and allusion to Kierkegaard in Bohr's more philosophically oriented writings, and also notes that Høffding's university lectures, which Bohr attended in his undergraduate days, gave prominence to Kierkegaard's thought.⁴⁸ Of particular importance for Bohr were Kierkegaard's "qualitative dialectic," which emphasizes antithesis between thought and reality that is not subsequently resolved by synthesis, his belief that thought could therefore never grasp the real, his stress on pragmatic thought, his emphasis on the necessity of choice, and his disdain for systems.⁴⁹ This sums up the epistemology of complementarity quite nicely and surely indicates that Kierkegaard indirectly placed his stamp on quantum physics through Bohr.

Bohr's philosophy of science, which was the subject of much contention with Einstein, is an amalgamation of positions inherited from Høffding, Kant, and Kierkegaard, and possibly James as well. In the main, Bohr's is an anti-realist/instrumentalist approach to science. This is illustrated well by Bohr's response to a question about whether or not the mathematical formalism of quantum theory could be assumed to mirror quantum reality. "There is no quantum world," he said. "There is only an abstract quantum mechanical description. It is wrong to think that the task of physics is to find out how nature *is*. Physics concerns what we can say about nature."⁵⁰ Inheritor's of Bohr's tradition have often taken him to mean by this that physical reality cannot be ascribed to quantum entities that are not under observation.⁵¹ Roger Penrose reads Bohr in this way,

⁴⁷Ibid., 171.

⁴⁸Jammer, *Conceptual Development*, 179.

⁴⁹Holton, "Roots," 280; Jammer, *Conceptual Development*, 179-80.

⁵⁰Bohr cited in Max Jammer, *The Philosophy of Quantum Mechanics: The Interpretations of Quantum Mechanics in Historical Perspective* (New York: John Wiley & Sons, 1974), 12.

⁵¹Arkady Plotnitski, "Complementarity, Idealization, and the Limits of Classical Concepts of Reality," in *Mathematics, Science, and Postclassical Theory*, ed. Barbara Herrnstein Smith and Arkady Plotnitsky (Durham, NC: Duke University Press, 1997), 142.

and believes he set the example for many physicists who followed him.

Many physicists, taking their lead from the central figure of Niels Bohr, would say that there is *no* objective picture at all. Nothing is actually ‘out there’, at the quantum level. Somehow, reality emerges only in relation to the results of ‘measurements’. Quantum theory, according to this view, provides merely a calculational procedure, and does not attempt to describe the world as it actually ‘is’.⁵²

Norris thinks Bohr’s philosophy of science is an amalgamation of realist and instrumentalist views, where knowledge is applicable to the phenomenal realm generally but not quantum reality specifically because our concepts are simply inadequate to grasp quantum nature.⁵³ Norris believes this pushes Bohr in an instrumentalist direction, which values success of experimentation to the neglect of any talk of how or why the experiments succeed. Importantly, this instrumentalism is joined to a form of realism in Bohr, with the result that quantum theory can advance no farther in the attempt to understand quantum ontology.

Bohr’s philosophy – and that of his followers – more often works out as a kind of hybrid instrumentalist-realist doctrine whereby these problems of interpretation are effectively raised into a full-scale quantum ontology which treats them as pertaining to the ultimate nature of things and hence as blocking any possible advance towards a properly realist alternative theory [of quantum physics]⁵⁴

Given the fact that Bohr so emphasizes the impossibility of ever elucidating the current conceptual block toward realism, Norris believes Bohr’s philosophy becomes rather anti-realist after all.⁵⁵ Additionally, given the CI’s emphasis on quantum indeterminacy apart from observation, it is indeed difficult to see how some form of anti-realism does not rightly describe Bohr’s philosophy of science. James Cushing appears to disagree with Norris. Bohr does deny a link between observed properties and those actually possessed by the independently existing quantum entity, Cushing acknowledges, but he

⁵²Roger Penrose, *The Emperor’s New Mind: Concerning Computers, Minds, and the Laws of Physics* (Oxford: Oxford University Press, 1989), 226.

⁵³Christopher Norris, *Quantum Theory and the Flight from Realism: Philosophical Responses to Quantum Theory* (New York: Routledge, 2000), 9.

⁵⁴*Ibid.*, 198.

⁵⁵Norris, *Against Relativism*, 112.

does not deny that some sort of (unknowable) reality exists apart from observation.⁵⁶ I believe Cushing here acknowledges that Bohr held a soft form of anti-realism—one that acknowledges the reality of the unobserved, non-conceptualized noumenal-like world—but denies that he espoused the more consistent variety of anti-realism—one that says the world “out there” does not in any sense exist independent of us. Possibly Cushing is correct to make this distinction in Bohr, but I believe there is sufficient cause to hold open the possibility that Bohr’s position may cross over into the more radical form of anti-realism, with regard to quantum entities at least. It is a difficult matter to decide. Certainly Bohr’s disciples have taken both routes. John Wheeler’s talk of a participatory-universe seems to fit nicely with radical anti-realist conceptions, while Penrose and John Gribbin seem more intent on towing a minimally anti-realist line.

Summary on Bohr. Bohr’s lifelong preoccupation with topics in philosophy significantly colored his involvement in quantum physics. Where physicists who were less concerned with philosophical issues, or where physicists such as Einstein who held to more classical views of science and philosophy have concluded that the anomalous features of quantum science are evidence that quantum theory is as yet incomplete, Bohr was predisposed, due to his affiliations with philosophical themes in Kant, Kierkegaard, Høffding, and others, to build quantum theory around the anomalies and declare the project complete. The end result is a fundamentally irrational conception of quantum reality which, as Bohr himself notes, has close affinities with elements of the Eastern worldview.

Wolfgang Pauli and Werner Heisenberg

As was the case with Bohr, Wolfgang Pauli and Werner Heisenberg were predisposed to find elements of irrationality in quantum physics. This is especially so with

⁵⁶James T. Cushing, “Foundational Problems in and Methodological Lessons from Quantum Field Theory,” in *Philosophical Foundations of Quantum Field Theory*, ed. Harvey Brown and Rom Harré (Oxford: Clarendon Press, 1988), 29-30.

Pauli, who embraced irrational concepts more fully than any other major figure in the development of quantum theory. Interestingly, his fondness for such views was related to his aversion to materialism.

The idea of the ‘detached observer’ is characteristic of the materialistic world view which subordinates the spiritual component of reality to the material one. The idea of the *anima mundi*, the world soul, has been completely expelled from the scientific world view. The indeterminism of the atomic world gave Pauli reason to speak of the return of the *anima mundi* (in a new sense of the world).⁵⁷

Borrowing from Schopenhauer, Pauli conceived of this world soul as a union of will and idea, where *idea* corresponds to a rational, conservative element of existence, and *will* corresponds to an irrational, creative element.⁵⁸ In this connection, Pauli believed his calling was to develop a framework that would unite psychology and physics.⁵⁹ Quantum theory seemed ideally suited to this task, for in Pauli’s opinion it had uncovered the irrational element of reality that Western thought had long suppressed. In particular, it was the indeterminism of quantum theory that most clearly indicated irrationality as a genuine feature of nature. For this reason Pauli opposed the hunt for deterministic factors and even regarded it as dangerous insofar as it might encourage the younger generation of physicists to hold out against the irrationality/freedom Pauli so gladly embraced.⁶⁰

The Copenhagen Cohort is sometimes classified as positivistic in the literature, but probably Pauli comes closest to bearing that label out. Early in his career Pauli held clearly to positivism in his philosophy of science, a position he had inherited from Ernst Mach, his godfather.⁶¹ With maturation, however, Pauli came to espouse what Tongdong

⁵⁷Laurikainen, “Wolfgang Pauli’s Conception,” 211.

⁵⁸Ibid., 215. Pauli explicitly named Schopenhauer, Lao-tse, Bohr and Indian mysticism as the chief sources for his philosophy. See Tongdong Bai, “Philosophy and Physics: Action-At-A-Distance and Locality” (Ph.D. diss., Boston University, 2004), 181, 183.

⁵⁹Herbert Van Erkelens, “Wolfgang Pauli and the Spirit of Matter,” in *Symposium on the Foundations of Modern Physics 1990: Quantum Theory of Measurement and Related Philosophical Problems*, ed. Pekka Lahti and Peter Mittelstaedt (Singapore: World Scientific, 1991), 431.

⁶⁰K. V. Laurikainen, *Beyond the Atom: The Philosophical Thought of Wolfgang Pauli* (Berlin: Springer-Verlag, 1988), 30.

⁶¹K. V. Laurikainen, “Wolfgang Pauli and the Copenhagen Philosophy,” in *Symposium on the Foundations of Modern Physics: 50 Years of the Einstein-Podolsky-Rosen Gedankenexperiment*, ed. Pekka

Bai labels a “dark, pessimistic, irrational, and holistic realism”⁶² The potency of Bai’s description becomes especially apparent in light of the following extended quote from Pauli, cited in Bai.

I would like to interpret the *dark* as that which, for the time being, eludes intellectual, regular (= ‘light’) order. That is the evil in ethics (the problem of the integration of the evil in the divinity, etc.), the *acausal* in natural philosophy. . . . It appears to me that in the early Renaissance the *darkness* which had been suppressed by Christianity wanted to become free . . . but that which followed in the 17th century (from Galileo to Descartes) was, on the contrary, the expansion of the realm of the luminous God into the newly recognized order of nature (illuminated by causality). Today we are once again confronted by darkness, evil, and the *acausal*, that is to say, by that which resists ordering into regularities. For me *Bohr* remains *the* thinker who made the counter position to ‘crystal clear’ Platonism comprehensible. He taught me (as early as the 1920’s) to recognize the pair of opposites ‘clarity-truth,’ as well as the pair of opposites ‘instinct-reason’ . . . and he *always* showed us how the actuality of the unique (whether it be of observation or of individual life) at any time restricts the utility and extension of *one* of the two elements of a pair of opposites at the expense of the other, how for this reason every philosophy *must* begin with a paradox!⁶³

Bai goes on to mention Pauli’s dislike for the Christian religion, which stemmed primarily from Pauli’s rejection of the commonly expressed Christian apologetic that says evil has no ontological existence but is merely a privation of good.⁶⁴ The Christian position, Pauli thought, refuses to deal with the irrationality (which Pauli equated with evil) revealed by quantum physics, and so is rejected by virtue of its inability to incorporate empirical data.

Bai concludes that Pauli’s worldview was a result of his studies in quantum

Lahti and Peter Mittelstaedt (Singapore: World Scientific Publishing, 1985), 274.

⁶²Bai, “Philosophy and Physics,” 179. Bai describes how Pauli’s views differ from positivism as follows: “Unlike the positivist claim that there might be another reality behind the instrumental formalisms of [quantum mechanics] but it is secondary to the primary reality of experience . . . Pauli insists on the existence of this irrational yet real individuality and claims that this dark reality is the ultimate reality of the micro-world; there is nothing behind it; and it is the reason for and the ultimate foundation of the statistical description of quantum formalism. This dark and irrational side of reality had been suppressed since the beginning of modern sciences till the development of [quantum mechanics].” *Ibid.*, 208.

⁶³*Ibid.*, 195-96. Bai elsewhere says Pauli’s worldview is “mystical holism, or pessimistic, dark, and irrational *realism*. That is, according to Pauli’s world-view, the existence of external reality, a crucial feature of the ‘table-thumping’ realism, is not questioned. What he insisted and thumped on is that reality itself has a hopelessly irrational and ‘dark’ side, shown by the irrational side of [quantum mechanics].” *Ibid.*, 183.

⁶⁴*Ibid.*, 196.

physics, and not vice versa.⁶⁵ No doubt there is some truth to this, but, contra Bai, it seems clear that Pauli's philosophical predispositions led him to instantiate and celebrate irrationalist themes in the interpretation of quantum science. This claim seems especially likely in light of Pauli's opposition to materialism, which no doubt predated his involvement in helping to develop the CI. It is also evinced in his outright opposition to the search for hidden variables for quantum physics, an opposition that was fueled by his concern that hope for such variables might prompt physicists and philosophers to go off chasing rational concepts of nature again and forever close the window to irrational conceptions of nature that quantum theory had seemingly opened. This aversion to hidden variables and the possible recovery of rationality in quantum physics indicates that Pauli operated with an a priori bias favoring irrationality. Thus, Pauli's worldview was not the mere result of his involvement in quantum physics. Rather, his involvement in quantum physics was significantly shaped by his prior commitment to the philosophies of Laotse, Schopenhauer, Indian mysticism, and, later on, Bohr himself.

As for Heisenberg, he saddled physicists and philosophers with one of the chief conceptual difficulties in the history of science: the quantum measurement problem. As discussed above, in his paper on the Uncertainty Principle Heisenberg asserted that the so-called wave-function collapses upon being measured, such that the native indeterminacy of the quantum system (by which it is said to manifest a superposition of all potentialities simultaneously) is reduced to a set of determinate values. Measurement *creates* rather than discovers the values of quantum systems. Fortunately, we are not left to wonder what ideologies fired Heisenberg's imagination as he took this most unprecedented turn in scientific theory-making, for in fact he tells us plainly that it came from without the bounds of physics, as Beller indicates in the following.

The source of this idea, as Heisenberg pointed out just a few years later, in 1932, during his lecture at the Academy of Science in Saxony, was Fichte's philosophy of self-limitation of the ego: 'The observation of nature by man shows here a close

⁶⁵Ibid., 212.

analogy to the individual act of perception which one can, like Fichte, accept as a process of the *Selbst-Beschränkung des Ich* (self-limitation of the ego).’ Heisenberg explicated Fichte’s idea in the following way: ‘It means that in every act of perception we select one of the infinite number of possibilities and thus we also limit the number of possibilities for the future.’ These words are almost identical with the concluding lines of the uncertainty paper: ‘Everything observed is a selection from a plenitude of possibilities and a limitation on what is possible in the future.’⁶⁶

Beller also says social pressure inclined Heisenberg to take the peculiar direction represented in his work on measurement and uncertainty.⁶⁷ The role society played in the development of the CI will be treated more carefully below in the discussion of the Forman Hypothesis.

There is also some indication that Heisenberg aimed to be something of a “new Kant,” for his mentor, Arnold Sommerfeld, had in the months before Heisenberg wrote and delivered his paper on the Uncertainty Principle called for just such a figure to arise and address the problem of causality in physics. Following this, Heisenberg presented his new ideas and billed them as an abandonment of the “Kantian category of causality.”⁶⁸ The attention he garnered from this must have thrilled Heisenberg, who was widely known to have an “insatiable drive” for success and distinction in everything he did, which included an overt attempt to leave a mark in philosophy.⁶⁹

Summary on Pauli and Heisenberg. Pauli and Heisenberg were ideally suited to team up with Bohr and rewrite fundamental conceptions of the physical world because they were, like Bohr, wildly ambitious, and because they were caught up in the irrationalist spirit of the Weimar culture, as discussed in greater detail below. Uncertainty and acausality were seen as exit ramps from the industrialist, mechanistic highway to destruction. The attempt to save quantum theory from such irrationality must have seemed

⁶⁶Beller, *Quantum Dialogue*, 67.

⁶⁷*Ibid.*, 109.

⁶⁸*Ibid.*, 195.

⁶⁹David C. Cassidy, “Heisenberg, Uncertainty and the Quantum Revolution,” *Scientific American* 266 (May 1992): 106; Beller, *Quantum Dialogue*, 195.

contrary not only to the empirical returns the Copenhagen physicists were getting from their experiments, but contrary to the well-being of their war-battered culture as well.

David Bohm's Alternative Interpretation

David Bohm was an American-born physicist who came to personify the resistance movement in quantum physics. He received a fine physics education, was trained in the Copenhagen tradition, but had a difficult time grasping exactly what Bohr's CI meant. Finally, the young Bohm decided he might come to understand Bohr's interpretation if he attempted to write a textbook from that viewpoint, the CI.⁷⁰ The book, *Quantum Theory*, was well received and is to this very day considered to be a noteworthy explanation of Bohr's views. However, for Bohm the result of the book was the realization that he needed to look for an alternative to the confusions instantiated in the CI.⁷¹

The alternative interpretation Bohm eventually presented is complicated and not altogether attractive to traditional Western thought, let alone that of the evangelical Christianity. I will discuss only the points relevant to the following claims: Bohm's alternative interpretation is more classical than Bohr's CI, and it is empirically equivalent to the CI as well, which means both interpretations are on equal footing so far as strictly scientific qualifications are concerned.

Of first importance, while Bohm's interpretation concedes that quantum systems must currently be described probabilistically, it nevertheless preserves intact the larger portion of the metaphysic associated with classical mechanics.⁷² A key to Bohm's

⁷⁰David Bohm and B. J. Hiley, "The de Broglie Pilot Wave Theory and the Further Development of New Insights Arising Out of It," *Foundations of Physics* 12 (1982): 1014.

⁷¹Jammer notes that Bohm's discussions with Einstein about this book marked a turning point for Bohm. Einstein, who opposed the CI from the start, was no doubt eager to see a bright young physicist attempt to displace the orthodox interpretation. Jammer also believes Bohm may have been emboldened by reading some articles from a materialist/determinist standpoint. Max Jammer, "David Bohm and His Work—On the Occasion of His Seventieth Birthday," *Foundations of Physics* 18 (1988): 692.

⁷²David Z. Albert, *Quantum Mechanics and Experience* (Cambridge, MA: Harvard University Press, 1992), 134; Cushing, "Copenhagen Hegemony," 97.

preservation of classical conceptions of physics in quantum theory is his allowance that hidden variables may be operative in quantum systems. This, of course, is contrary to the CI's insistence that hidden variables are impossible in quantum physics—a move that codifies ontological indeterminism. Bohm insists that the orthodox interpretation cannot prove this to be so, especially inasmuch as it is possible to formulate an alternative interpretation which keys on hidden variables, is logically consistent, and leads to exactly the same results for quantum processes.⁷³ Bohm describes the key features of his proposal, and how it preserves causality, in the following passage from the second of his groundbreaking 1952 articles.

In the usual interpretation of the theory, it is stated that although each measurement admittedly leads to a definite number, nothing determines the actual value of this number. The result of each measurement is assumed to arise somehow in an inherently indescribable way that is not subject to a detailed analysis. Only the statistical results are said to be predictable. In our interpretation, however, we assert that the at present 'hidden' precisely definable particle positions and momenta determine the results of each individual measurement process, but in a way whose precise details are so complicated and uncontrollable, and so little known, that one must for all practical purposes restrict oneself to a statistical description of the connection between the values of these variables and the directly observable results of measurements. Thus, we are unable at present to obtain direct experimental evidence for the existence of precisely definable particle positions and momenta.⁷⁴

One of the convictions that drove Bohm's belief that hidden variables were operative in quantum phenomena was the fact that, historically speaking, whenever scientists have suggested statistical theories the appearance of genuine randomness was subsequently overturned by the discovery of laws explicable in terms of hidden variables.⁷⁵

⁷³David Bohm, "A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables. I," *Physical Review* 85 (1952): 166. Some commentators have criticized Bohm's use of the term "hidden" to describe the causal variables presently unknown in quantum physics, believing it sounds perhaps more mysterious than anything the CI posits. Jeremy Butterfield and Christopher Isham suggest we replace "hidden variables" with "extra values" to eliminate the appearance of mystery. See Jeremy Butterfield and Christopher Isham, "Spacetime and the Philosophical Challenge of Quantum Gravity," in *Physics Meets Philosophy at the Planck Scale: Contemporary Theories in Quantum Gravity*, ed. Craig Callender and Nick Huggett (Cambridge: Cambridge University Press, 2001), 49-50.

⁷⁴David Bohm, "A Suggested Interpretation of the Quantum Theory in Terms of 'Hidden' Variables. II," *Physical Review* 85 (1952): 183.

⁷⁵Bohm, "A Suggested Interpretation . . . I," 168.

Bohm explains and illustrates this claim in an important passage from his book,

Wholeness and the Implicate Order.

When it was discovered that spores and smoke particles suffer a random movement obeying certain statistical laws (the Brownian motion) it was supposed that this was due to impacts from myriads of molecules, obeying deeper individual laws. The statistics were then seen [i.e., assumed] to be consistent with the possibility of deeper individual laws, for, as in the case of insurance statistics, the overall behaviour of an individual Brownian particle would be determined by a very large number of essentially independent factors. Or, to put the case more generally: *lawlessness of individual behaviour in the context of a given statistical law is, in general, consistent with the notion of more detailed individual laws applying in a broader context.*

In view of the above discussion, it seems evident that, at least on the face of the question, we ought to be free to consider the hypothesis that results of individual quantum-mechanical measurements are determined by a multitude of new kinds of factors, outside the context of what can enter into the quantum theory. These factors would be represented mathematically by a further set of variables, describing the states of new kinds of entities existing in a deeper, sub-quantum-mechanical level and obeying qualitatively new types of individual laws. Such entities and their laws would then constitute a new side of nature, a side that is, for the present ‘hidden’. But then the atoms, first postulated to explain Brownian motion and large-scale regularities, were also originally ‘hidden’ in a similar way, and were revealed in detail only later by new kinds of experiments⁷⁶

Bohm’s point comes down to this: we are justified to assume that the apparent indeterminism in quantum phenomena is merely a reflection of the fact that we do not yet know everything there is to know about quantum nature.⁷⁷ There must be a “hidden” aspect to quantum nature that is somewhat analogous to the way atomic nature was “hidden” from experimenters who first offered statistical explanations for Brownian motion. As for those physicists and philosophers who deny that deeper, causal factors will ever be discovered in quantum physics, Bohm concludes that they are guilty of circular reasoning since the conclusion that no deeper level exists follows only if one has determined a priori that no such level exists.⁷⁸

⁷⁶David Bohm, *Wholeness and the Implicate Order* (Boston: Routledge & Kegan Paul, 1980), 68.

⁷⁷Albert says that “on Bohm’s theory, the world can only appear to us to evolve *probabilistically* . . . in the event that we are somehow *ignorant* of its exact state. And so the very *idea* of probability will have to enter into [Bohm’s] theory as some kind of an *epistemic* idea, just as it enters into classical statistical mechanics.” Albert, *Quantum Mechanics*, 135.

⁷⁸David Bohm, *Causality and Chance in Modern Physics* (Philadelphia: University of Penn

As for the uncertainty problem in quantum measurement, Bohm distances himself from the Copenhagen claim that the uncertainty is inherent both to quantum nature and our inability properly to conceive models for that nature.

In our interpretation . . . the uncertainty principle is regarded, not as an inherent limitation on the precision with which we can correctly conceive of the simultaneous definition of momentum and position, but rather as a practical limitation on the precision with which these quantities can simultaneously be measured, arising from unpredictable and uncontrollable disturbances of the observed system by the measuring apparatus.⁷⁹

So, in Bohm's interpretation, quantum particles *do* have precise simultaneous values of position and momentum, and our inability to isolate these is a reflection of the limitations of our measuring devices and procedures.⁸⁰ There is no "collapse" upon measurement, which means Bohm eliminates the measurement problem as construed by the CI. The only "problem" is epistemological rather than ontological. Bohm also escapes the demarcation problem that dogs the CI.⁸¹ Recall that the CI has tremendous difficulty justifying where it draws the line between quantum and non-quantum systems. One quantum particle behaves in accordance with quantum nature, but how many quantum particles can we add together before a system passes from quantum to non-quantum behavior? Rather than arbitrarily splitting the world between quantum and non-quantum system, Bohm's interpretation allows for a continuous conceptual passage from the micro- to the macro-domain, and vice versa. Granted, we cannot treat quantum and non-quantum systems alike experimentally, but as Bohm says, this is not due to quantum nature being fundamentally contrary to that of the macro-world, as the CI concludes, but rather it is due to the epistemological and experimental sorts of limitations named above—we de-

sylvania Press, 1957), 95.

⁷⁹Bohm, "A Suggested Interpretation . . . II," 180.

⁸⁰Norris, *Quantum Theory*, 2-3; Cushing, *Quantum Mechanics*, 52.

⁸¹John Bell says Bohm's most important accomplishment was "the elimination of any need for a vague division of the world into 'system' on the one hand, and 'apparatus' or 'observer' on the other." John Bell, "Beables for Quantum Field Theory," in *Speakable and Unspeakable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 173.

scribe quantum systems statistically rather than classically because there are things about such systems that we currently cannot grasp due to presently unknown factors and inadequate machinery.

Thus far we've seen how Bohm's theory differs from the CI in what it *concludes* about issues such as hidden variables, uncertainty, and causality. But *how* does Bohm's theory justify the differences? As Albert explains, it all comes down to Bohm's postulation that the wave-function, which on the orthodox view is merely a non-physical, mathematical description of the superposition of all possible states for the quantum system, is an actual physical entity.

The *quantum-mechanical wave functions* are conceived of in this theory as genuinely physical *things*, as something somewhat like force fields (but not quite), and anyway as something quite distinct from the particles; and the laws of the evolutions of these wave functions are stipulated to be precisely the linear quantum-mechanical equations of motion (always, period; wave functions never collapse on this theory); and the *job* of these wave functions in this theory is to sort of *push the particles around* (as force fields do), to *guide* them along their proper *courses*; and there are additional laws in the theory (new ones, *un-quantum-mechanical* ones) which stipulate precisely how they do that.⁸²

In the end, what Bohm has crafted in his interpretation of quantum mechanics is a thoroughly realist counterpart to the problematic realist/anti-realist/instrumentalist conceptions in the CI. Norris helpfully explains that Bohm's realism is premised on the vital realist assumption that a satisfactory interpretation of quantum physics will do more than just satisfy demands for "predictive correlation or empirical warrant."

That is to say, [a realist approach] will work on the joint principles that (1) the reality underlying those phenomena might always turn out to exceed or transcend our current methods of empirical verification, and (2) this entails a method of inference to the best causal-explanatory theory consistent with the evidence at hand.⁸³

Norris goes on to explain that the orthodox interpretation diverges from realism in that it is content to accept mere empirical verification as the proper stopping point for a satisfactory account of quantum theory, which action leaves interpreters short of un-

⁸²Albert, *Quantum Mechanics*, 135.

⁸³Norris, *Quantum Theory*, 27.

derstanding the substance underlying the phenomena. Bohm blows past this artificial limitation and seeks to judge interpretive options on the basis not just of empirical adequacy, but also on their ability to yield causal-explanatory power. Importantly, if this means Bohm must journey past current empirical justification, so be it, for he's off hunting for explanatory essence—a necessary component of any genuinely realist interpretation of physical theory. Finally, Norris points up the fact that science would not exist if scientists had historically operated under the strict empiricist criterion for theory-selection that the CI employs.⁸⁴ After all, if scientists were allowed to introduce interpretations only when sufficient evidence existed for them, never venturing out to suggest the existence of empirically unverified variables, how could we have progressed past a rudimentary form of science? And most important of all, the completeness theorem, by which the CI maintains that quantum theory is incapable of supplementation, is empirically unverifiable. It seems difficult to deny that in principle it is always possible that future discoveries will supplement the well-grounded theories that we have generally taken to be complete.

Thus, it is clear that Bohm and others who seek an alternative interpretation to quantum theory are justified in doing so just so long as they are operating from a realist conception of science. The worst thing the Copenhagen theorist can throw at them is the charge that they are going past empirical warrant, but this will not phase the realists, for they admit straightaway that they are off trying to fetch explanatory power, which they take to be a vital component of any adequate scientific theory. Hence, the only potentially fatal salvo the orthodox theorist can put over against the realist is this: the charge that alternatives to the CI do not account for the empirical results we *do* have from the laboratories. In fact, this charge is not available to the Copenhagen theorist, for Bohm's theory happens to be empirically equivalent in all respects.⁸⁵ In other words, what the CI can

⁸⁴Ibid.

⁸⁵Jammer, "David Bohm and His Work," 693; Trevor J. Pinch, "The Hidden-Variables Controversy in Quantum Physics," *Physics Education* 14 (1979): 50; Albert, *Quantum Mechanics*, 134.

successfully predict in the laboratory, Bohm can likewise predict. This sameness is a result of the fact that both interpretations use the same mathematical formalism. The math is the same in Bohr and Bohm, but their metaphysics—their *interpretation*—differs significantly. What this means is there is “pervasive underdetermination” between these competing interpretations.⁸⁶ Or, at least, *empirical* underdetermination. The fact is, when interpreters are faced with empirical equivalence between two or more theories, they are free (compelled, really) to make their judgment based on the philosophical and epistemological virtues of the options before them.⁸⁷ In other words, one’s metaphysical preferences will decide which interpretive option is deemed most suitable.⁸⁸ In that case, the realist is absolutely justified if he chooses Bohm or some other alternative explanation that is empirically equivalent to the standard interpretation.

Bohm Rejected

Bohm’s rendering of quantum theory is highly significant insofar as it speaks against the propriety of the Copenhagen hegemony. Due to the role metaphysical predilection plays in directing each theorist’s selection among interpretive options, it should be the case that the CI is barred from enjoying privileged status over competing interpretations. Furthermore, interpretations that retain more of the classical metaphysics and physics ought especially to gain a fair hearing, but this has not happened in Bohm’s case. There are several reasons why this is so.

First, Bohm failed to gain early momentum among realists. For instance, Einstein, the stalwart and ever-vocal foe of Bohr’s interpretation, listened with great interest

⁸⁶James T. Cushing, “Underdetermination, Conventionalism and Realism: The Copenhagen vs. the Bohm Interpretation of Quantum Mechanics,” in *Correspondence, Invariance and Heuristics: Essays in Honour of Heinz Post*, ed. Steven French and Harmke Kamminga (Boston: Kluwer Academic Publishers, 1993), 262.

⁸⁷J. P. Moreland, *Christianity and the Nature of Science: A Philosophical Investigation* (Grand Rapids: Baker, 1989), 28.

⁸⁸John Polkinghorne, *Science and the Trinity: The Christian Encounter with Reality* (New Haven, CT: Yale University Press, 2004), 76.

to Bohm's proposal and then rejected it flatly. Bohm describes Einstein's reaction as "not at all enthusiastic" and believes the reason Einstein reacted thus was the instantiation of non-locality in the interpretation.⁸⁹ Though Einstein appreciated the fact that Bohm retained causality in quantum physics, he believed that all causality ought to be local. Thus, Einstein believed that Bohm's postulation of *non-local* causality was simply too great a concession to standard quantum theory. As radical a departure as Bohm had made from the larger community of quantum physicists, Einstein was calling for something far more revolutionary.⁹⁰ This Bohm could not deliver, and so his theory was rejected by the Copenhagen theorists and shunned by those who shared his displeasure with Copenhagen.

A second reason Bohm's interpretation has failed to garner wide support among realists is that, simply put, there is essentially as much "oddness" in it as there is in the standard interpretation. For example, Bohm embraces holism so completely that he is even willing to say that inanimate matter may implicitly contain something analogous to mind.⁹¹ All space, which we mistakenly sense to be empty, is actually the plenum that grounds all existence. Enfolded within the plenum is an implicate order that applies to both matter and consciousness, enabling us to speak of a common ground for each in a way that, according to Bohm, resembles Leibniz's monads and Whitehead's actual occasions.⁹² Part of what drives Bohm in this direction, as Laurikainen explains, is his emphasis on non-local causality—the very thing that troubled Einstein. The long-distance influences, or, non-local hidden variables Bohm introduces pictures a world in which

⁸⁹Bohm and Hiley, "The de Broglie Pilot Wave Theory," 1014-15. See also, Cushing, *Quantum Mechanics*, 147. On Bohm's interpretation involving non-locality, Bell says it is "grossly non-local," while Greene has called it "brazen" and "blatant" non-locality. See John Bell, "On the Einstein-Podolsky-Rosen Paradox," in *Speakable and Unsayable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 14; Brian Greene, *The Fabric of the Cosmos: Space, Time, and the Texture of Reality* (New York: Knopf, 2004), 121-22.

⁹⁰Cushing, *Quantum Mechanics*, 148.

⁹¹Donald Factor, *Unfolding Meaning: A Weekend of Dialogue with David Bohm* (Gloucestershire, UK: Foundation House Publications, 1985), 20-21.

⁹²Bohm, *Wholeness*, 191-207.

everything influences everything else, such that the universe can be described as an indivisible wholeness.⁹³

A third reason Bohm's interpretation did not gain significant purchase is that it was heartily received by Marxists.⁹⁴ The Marxists were correct to see Bohm's theory as suitable to their worldview, for Bohm clearly manifested a dialectical materialist agenda.⁹⁵ The fact that Bohm introduced his interpretation during the early stages of the Cold War made the Marxist celebration of his interpretation a particularly ominous fact, so ominous, in fact, that the American government took notice. In 1949 Bohm was asked to present himself before the Congressional Un-American Affairs Committee. When he was asked directly if he was a card-carrying Communist, Bohm refused to answer by pleading his rights under the Fifth Amendment. After being charged with and subsequently acquitted for contempt of Congress, Bohm lost his job at Princeton and then left America permanently.⁹⁶ Despite his fondness for materialist themes it is not clear how much Bohm may have sympathized with the Communist Party specifically.⁹⁷ What is certain is that the association of Bohm's interpretation with materialism ensured that few physicists would give Bohm a second glance.⁹⁸

Finally, Bohm's work was also ignored simply because another interpretation was firmly in place. Robert Oppenheimer once declared that he was sure that Bohm's alternative was incorrect. When asked if he had actually read Bohm, Oppenheimer reluctantly admitted that he had not and that *no one* had seriously done so.⁹⁹ Trevor Pinch be-

⁹³Laurikainen, "Wolfgang Pauli's Conception of Reality," 215.

⁹⁴Andrew Cross, "The Crisis in Physics: Dialectical Materialism and Quantum Theory," *Social Studies of Science* 21 (1991): 744.

⁹⁵Laurikainen, "Wolfgang Pauli's Conception of Reality," 217.

⁹⁶Cross, "The Crisis in Physics," 742.

⁹⁷Albert insists that Bohm was no Communist, and that coping the Fifth Amendment was a matter of principle rather than an admission of guilt. David Z. Albert, "Bohm's Alternative to Quantum Mechanics," *Scientific American* 270 (May 1994): 62.

⁹⁸Cross, "The Crisis in Physics," 753.

⁹⁹Cushing, *Quantum Mechanics*, 157.

believes such rejections evince a sociological factor in science generally and quantum physics specifically.

The interests of the establishment clearly lay in the orthodox view of quantum theory which had proved to be such a successful theory, while Bohm's interests were in trying to establish a radical new basis to the quantum theory which might prove more successful as physics entered new domains. Such a clash of interests is almost bound to produce the type of acrimony which we normally associate with overtly social conflicts but which is generally hidden in science. The significance of such clashes is that they show that scientific knowledge, produced by humans, is *ipso facto* permeated by social influences.¹⁰⁰

Commenting during the early stages of Bohm's rejection by the physics community, Hans Freistadt concluded that the "vehemence of the criticism" leveled against Bohm's alternative indicated the degree to which the society of scientists had gone over to positivism.¹⁰¹

For our purposes, the most important things to note about Bohm's interpretation are that it is empirically equivalent to the CI—and thus is no less verified scientifically—and that it preserves more of the classic presuppositions about causality and the definite reality of nature apart from the human observer. In the end, I believe Bohm's interpretation—especially in its emphases on holism, materialism, and matter-based consciousness—is problematic for adherents to a Christian worldview. Nevertheless, the very existence of Bohm's empirically feasible alternative view is indication that the CI is but one of at least two options for interpreting quantum theory. Furthermore, I think it is reasonable to suppose that the justified existence of two competing interpretations to quantum theory indicates that quantum theory itself *is* incomplete, as Einstein insisted.

De Broglie's Pilot Wave

Bohm's alternative interpretation to quantum theory is undoubtedly the most serious contender that has come up against the CI, but in reality it is just a republication

¹⁰⁰Pinch, "The Hidden-Variables Controversy," 52.

¹⁰¹Hans Freistadt, "The Crisis in Physics," *Science and Society* 17 (1953): 229.

of something Louis de Broglie put forth at the 1927 Solvay conference where Bohr first introduced his complementarity doctrine. Called the pilot wave theory, de Broglie's suggestion was essentially that the quantum wave function was *not* a complete, final description of an indeterminate quantum system but rather a description of the means by which particle pathways are determined. Whereas the orthodox view says electrons are not really particles but "packets" formed by a composition of waves, which implies that quantum "particles" have no position until measurement takes place and the wave function is thereby collapsed, de Broglie suggested that quantum particles are genuinely particles prior to our measurements of them, and that they travel in intimate link with waves that pilot (guide) their pathway options. Implications include that the Uncertainty Principle is an epistemic rather than ontological limitation—quantum systems have objective values prior to measurement and our inability to discern them is a mark of our ignorance.¹⁰² Another important implication of de Broglie's pilot wave is that, contra the orthodox view, the quantum system is described as wave *and* particle. This means both genuinely exist simultaneously as separate but related entities, and that neither is indeterminate or indefinite apart from acts of measurement. Thus, where the orthodox view says the quantum system is wave *or* particle depending on what kind of observation is made, the de Broglie system says the system is always inhered by both wave and particle structures, and that our measurements can look for either one or the other of these real features, but never both simultaneously. De Broglie's suggestion obviously entails a much less specious variety of the measurement problem, for unlike the orthodox view, which says the choice in measurement will cause either wave or particle characteristics to be actualized in the system, de Broglie is merely saying that choices in measurement will select one or the other pre-existing characteristics of that system.¹⁰³

¹⁰²Norris, *Quantum Theory*, 15.

¹⁰³For helpful explanations of the pilot wave theory, see Cushing, *Quantum Mechanics*, 118-26, and Grometstein, *Roots*, 319.

Much like Bohm's interpretation, de Broglie's pilot wave theory was dismissed more by neglect than by close scrutiny. As would later be the case with Bohm's offering, the foremost scientific realist of the era, Einstein, dismissed de Broglie's alternative. Most likely he did so because he was busy trying to formulate his own theory on hidden variables and simply thought de Broglie was not approaching the matter correctly.¹⁰⁴ In any case, de Broglie never got his theory off the ground despite its merits. Bell points out that during his education he was not even told of de Broglie's scientifically feasible pilot wave theory, and then asks a series of illuminating questions. "Why is the pilot wave picture ignored in the textbooks? Should it not be taught, not as the only way, but as an antidote to the prevailing complacency? To show that vagueness, subjectivity, and indeterminism, are not forced on us by experimental facts, but by deliberate theoretical choice?"¹⁰⁵

Vagueness, subjectivity, and indeterminism may not be forced on us by the experimental facts, but to de Broglie it must have seemed clear that the physicists of his day were blind to this fact. So roundly was de Broglie denounced for his wandering from the orthodox fold that he quickly retracted his sensible suggestions and fell back in line with everyone else. He remained there until he came across Bohm's fresh work in the 1950s and again stepped out of line and into the small phalanx of physicists seeking causality and realism in quantum mechanics.

To this day that phalanx has made very little forward progress, and de Broglie's pilot wave theory is still almost entirely ignored. Bell makes the following summary of the value of de Broglie's and Bohm's work.

It is easy to find good reasons for disliking the de Broglie-Bohm picture. Neither de Broglie nor Bohm liked it very much; for both of them it was only a point of departure. . . . But like it or lump it, it is perfectly conclusive as a counter example to the

¹⁰⁴Cushing, *Quantum Mechanics*, 119.

¹⁰⁵John Bell, "On the Impossible Pilot Wave," in *Speakable and Unsayable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 160.

idea that vagueness, subjectivity, or indeterminism, are forced on us by the experimental facts covered by nonrelativistic quantum mechanics.¹⁰⁶

Thus, de Broglie's pilot wave comes in for much the same assessment as does Bohm's. We may not finally accept it as the complete and true interpretation of quantum physics, but it nevertheless gathers enough credence to count as yet another indicator that, contrary to prevailing opinion, the CI is not legitimately the only option on the table.

The Forman Hypothesis

Pinch stated above that scientific knowledge is permeated by social influence. This sort of statement could be taken to imply a basically anti-realist approach to science, but this is not a necessary conclusion to the realization that social factors can and do play roles in theory formation and selection among scientists. One may simply say that such factors do sometimes entice scientists away from the proper paths, and that the empirical fruitfulness of those paths is a counter-indicator to naïve realism, but not realism per se. The so-called Forman hypothesis is a compelling argument for the claim that this sort of thing has happened in quantum physics.

German social factors in the early twentieth century are particularly important for our consideration of the development of the CI, for the great majority of figures who lent content to that interpretation were German or Austrian.¹⁰⁷ Examination of relevant social factors provides evidence suggesting that Bohr and his associates were operating in a climate that may have inclined them to push quantum theory into an emphasis on irrational, acausal themes. Forman sets the background for his hypothesis nicely with the following summary of the German *zeitgeist* prior to the Great War.

Prior to and during the First World War German physicists had viewed their science, if not themselves, as closely allied with, and essential to, Germany's technically advanced industry, and with the economic and military power which that

¹⁰⁶Ibid., 163.

¹⁰⁷Paul Forman, "Kausalität, Anschaulichkeit, and Individualität, or How Cultural Values Prescribed the Character and the Lessons Ascribed to Quantum Mechanics," in *Society and Knowledge: Contemporary Perspectives in the Sociology of Knowledge*, ed. Nico Stehr and Volker Meja (New Brunswick, NJ: Transaction Books, 1984), 333.

industry ensured. Confident of their value in the eyes of the public, they were self-assured, even arrogant, vis-à-vis their colleagues in the humanities and social sciences. Then, however, Germany's completely unexpected military and industrial collapse at the end of 1918 brought an immediate and extreme public reaction against the industrial-scientific idols.¹⁰⁸

That immediate and extreme reaction included an unprecedented keenness for irrationality and existentialist philosophies as well as settled antagonism toward the exact sciences and their applications.¹⁰⁹ A particularly important element in this neo-romantic mood was an "antipathy toward causality."¹¹⁰ The physicists in particular supplied the backdrop for this cultural shift, for they had made possible the technological and industrial innovations that led to machination, war, and alienation from nature.¹¹¹ In this light, scientists in general became objects of scorn amidst the call for spiritual renewal.

This wave of anti-technologic *Lebensphilosophie* was a celebration of 'life,' intuition, unmediated and unanalyzed experience; it was a rejection of reason and logical analysis because allegedly inseparable from positivism-mechanism-materialism and because, as fundamentally disintegrative, unsatisfying of the 'hunger for wholeness.'¹¹²

If the physicists were to recover something of their former privilege, they needed to become more attuned to the new *Lebensphilosophie*. Casting aside the albatross of causality would be a first step toward that end.¹¹³ Importantly, several German physicists were already prone to delivering pronouncements against causality in the seven years that intervened between the end of the First World War and the introduction of Heisenberg's Uncertainty Principle.¹¹⁴ This seems to suggest the possibility that the

¹⁰⁸Paul Forman, "The Reception of an Acausal Quantum Mechanics in Germany and Britain," in *The Reception of Unconventional Science*, ed. Seymour Mauskopf (Boulder, CO: Westview Press, 1979), 12-13.

¹⁰⁹Paul Forman, "Weimar Culture, Causality, and Quantum Theory, 1918-1927: Adaptation by German Physicists and Mathematicians to a Hostile Intellectual Environment," in *Quantum Histories*, vol. 4 of *Science and Society: The History of Modern Physical Science in the Twentieth Century*, ed. Peter Galison, Michael Gordin, and David Kaiser (New York: Routledge, 2001), 193.

¹¹⁰Forman, "Kausalität," 337.

¹¹¹Ibid., 338.

¹¹²Forman, "The Reception," 13.

¹¹³Forman, "Weimar Culture," 218.

¹¹⁴Forman, "Kausalität," 338. See also, Forman, "The Reception," 14.

physicists were *hunting* for indeterminacy prior to “finding” it in quantum physics. At the very least they were preconditioned to find it readily wherever and whenever a hint of anomaly was found.

Forman is not the only scholar to note the role popular philosophical sentiment played in the development of quantum theory. Wise, writing about quantum physics and the cultural origins of indeterminism, says the idea of indeterminism came to prominence by 1920, and that it was always associated with a belief in “unanalyzable holism.”¹¹⁵ He then offers an explanation for how this came about.

In central Europe, particularly Germany, statistical causation acquired much of its meaning from the political-social ideal termed *Gemeinschaft* and from the idea prominent in psychology of a qualitative causation distinct from quantitative causation. *Gemeinschaft* connoted both essential unity in a whole society and essential diversity in its constituent individuals, while ‘qualitative causation’ determined the behavior of a complex system without determining the behavior of its parts, and did not reduce to causes acting on parts.¹¹⁶

Cushing notes that physicists split between causality and acausality along generational lines. Einstein, Schrödinger, and de Broglie, all of whom opposed the CI on significant points, represented the older generation of physicists and favored traditional concepts such as causality and locality. The younger generation was much more attuned to the philosophical flavor of the day, and so indeterminism was especially attractive to the several brilliant young physicists involved in the formulation of the CI.¹¹⁷ Sam Treiman agrees and says subsequent generations of physicists found it easier to incorporate such revolutionary concepts because they grew up learning such things.¹¹⁸

Finally, Hilary Putnam has said that the pair of 1927 conferences that ushered in the reign of the orthodox interpretation of quantum physics was as much about philosophy as it was about physics. In fact, he says the dispute over the interpretation of

¹¹⁵Wise, “How Do Sums Count?” 395.

¹¹⁶*Ibid.*

¹¹⁷Cushing, “Copenhagen Hegemony,” 95.

¹¹⁸Sam Treiman, *The Odd Quantum* (Princeton: Princeton University Press, 1999), 14.

quantum physics transcended all sorts of boundaries, such that issues of culture and metaphysic also came to the forefront.¹¹⁹

Assessing the Forman Hypothesis

Forman acknowledges that his “sociological model” cannot be the whole truth for explaining major shifts in scientific ideology, but nevertheless he is confident that the ideologies live in the early twentieth-century Weimar culture played a significant role in shaping the dominant view of quantum physics.¹²⁰ The science of quantum physics has no necessary link to either the philosophies the Copenhagen theorists built atop it or the philosophical implications they sought to draw from it. Rather, says Forman, the physicists made quantum theory to match the obligations given them by their dominant cultural milieu.¹²¹

Forman’s hypothesis has provoked thoughtful response and even qualified acceptance from scientific realists, which is perhaps surprising given the general fondness *anti*-realists display for sociological models for science. Cushing rejects what he calls the “extreme Forman hypothesis,” which says sociological factors played a central role in the *creation* of quantum theory, but adopts a “modest Forman-type thesis” by stating that such factors were important to winning acceptance for the radical new views in physics.¹²² Beller’s assessment is similar to Cushing’s in that she espouses a modified form of Forman’s hypothesis. “Somewhat modifying Forman’s argument, the cultural milieu provided a psychological reinforcement, as well as a vast and rich reservoir of arguments for legitimization, in the event of an ultimate conclusion favoring a clear case of indeterminism in physics.”¹²³

¹¹⁹Hilary Putnam, *Pragmatism: An Open Question* (Oxford: Blackwell, 1995), 15.

¹²⁰Forman, “Weimar Culture,” 220.

¹²¹Forman, “*Kausalität*,” 344.

¹²²James T. Cushing, *Theory Construction and Selection in Modern Physics: The S Matrix* (Cambridge: Cambridge University Press, 1987), 7.

¹²³Mara Beller, “Born’s Probabilistic Interpretation: A Case Study of ‘Concepts in Flux,’” in

As for the claim that the cultural milieu may have *caused* quantum interpretation to take an irrationalist direction, Beller rejects it. Oddly, this rejection comes despite the fact that she says the commitment to indeterminism “was conditioned mainly by theoretical possibilities and competitive dialogues over conflicting interpretational systems” among physicists.¹²⁴ I say this is odd because it seems clear that the physicists’ pool of “theoretical possibilities” was filled by the cultural milieu in which they found themselves. Likewise, the dominant *Zeitgeist* supplied much of the content of their dialogues. Thus, it seems that Beller’s conclusion that indeterminism won out among quantum physicists due to their assessment of theoretical possibilities as they engaged in competitive dialogues overlooks the fundamentally *sociological* nature of such a process. If the social milieu regards indeterminism as a preferred way of construing the world, surely physicists belonging to that social milieu will take quantum indeterminism to be notable or even preferable as a theoretical possibility. Conversely, if indeterminism is seen as far-fetched in the eyes of the culture, physicists would not be as likely to consider it to be worthy for consideration as a theoretical possibility.

James Gardner Murphy, an Irish literary figure who was well versed in physics and closely associated with major physicists, conducted an interview with Einstein in 1932 that serves as a powerful indication that a moderately strong version of the Forman hypothesis is preferable to the weakened versions Cushing and Beller adopt. After discussing the topic of indeterminism, which Einstein insists is merely subjective and not objective in quantum systems, Einstein moves on to claim that rather than ditch causality scientists must strive to “enlarge and refine” and thereby salvage its place in physics. Murphy’s reply to this claim is very important for assessing the Forman hypothesis.

You’ll have a hard job of it, because you’ll be going out of fashion. . . . Scientists live in the world just like other people. Some of them go to political meetings and

Quantum Histories, vol. 4 of *Science and Society: The History of Modern Physical Science in the Twentieth Century*, ed. Peter Galison, Michael Gordin, and David Kaiser (New York: Routledge, 2001), 249.

¹²⁴Ibid.

the theater and mostly all that I know, at least here in Germany, are readers of current literature. They cannot escape the influence of the *milieu* in which they live. And that *milieu* at the present time is characterized largely by a struggle to get rid of the causal chain in which the world has entangled itself.¹²⁵

Scientists do indeed live in the world just like other people. Politics, theater, and literature, as Murphy says, cannot fail to influence the theoretical posits of scientists. I conclude that the Weimar culture's fascination with irrationalist concepts such as genuine indeterminism and holism most likely played a noteworthy role in the development of similar themes in quantum theory. This conclusion is strengthened by the fact, noted above, that Bohr, Pauli, and Heisenberg all favored irrationalist elements in philosophy—the very elements adopted by their culture-at-large and inscribed into the interpretation of quantum physics at Bohr's Copenhagen laboratory.

Public Relations, America, and Historical Contingency

The Copenhagen interpretation of quantum physics comported nicely with philosophical and cultural tastes in central Europe during the post-war era, but what accounts for its dominance elsewhere? Cushing notes several significant advantages the Copenhagen theorists had over their competitors. Perhaps most important of all, the Copenhagen physicists were well organized. While Einstein, Schrödinger, de Broglie, and any other decided realists out there were working independently, each attempting to pull quantum theory into realism by different means, the Copenhagen group worked in near unison to achieve dominance in quantum physics.¹²⁶ An interesting example of how the orthodox theorists aligned themselves for victory is illustrated in how Max Born handled his early reservations about some of Bohr's philosophical contributions to the CI. Rather than squabble about these in public, Born kept them to himself for the sake of party unity.¹²⁷

¹²⁵Max Planck, *Where is Science Going?* (New York: W. W. Norton & Company, 1932), 204-05.

¹²⁶Cushing, *Quantum Mechanics*, 117.

¹²⁷Beller, *Quantum Dialogue*, 184.

The opportunity to be employed and thrive as physicists was part of what was at stake in the contest for interpretive prevalence. For instance, Cushing discusses the role career ambition played in Heisenberg's work as well as the work of his fellow Copenhagen theorists.

Not only did Heisenberg have personal ambitions for advancement, but several chairs in theoretical physics were opening up in Germany. There was a conscious realization by members of the Copenhagen school that control of the future direction of theoretical physics was at stake. This group had the talent, organization and drive to carry the day in establishing the hegemony of the Copenhagen view.¹²⁸

The hegemony spread to America and elsewhere for several of the same reasons it was established so thoroughly in Europe. The organization and ambition that marked the Copenhagen group is seen in their ambitious campaign to spread their ideas to the world via public and private lectures abroad. For instance, as part of their round-the-world tour in 1929, Paul Dirac joined with Heisenberg in touting the CI. Of particular importance was their stop in Chicago, where they lectured on the CI at the University of Chicago, a school of established and expanding influence in American science.¹²⁹ Heisenberg in particular was effective at spreading the Copenhagen gospel of liberation through indeterminism. He seemed readymade for the task, in fact. Like an orator trained to work the crowd, Heisenberg deftly adapted his presentation to his audiences. As Beller notes, for general audiences whose training in mathematics was minimal, Heisenberg stuck to positivist lines, but among the mathematically astute, he skipped over to a realist ontological construal of the Copenhagen interpretation.¹³⁰ Tickled ears heard what suited them best, and the CI rolled on to greater popularity each time Heisenberg and Dirac picked up and headed for the next stop on their speaking circuit.

American physicists, marked by pragmatist and can-do attitudes, were mostly ambivalent to the interpretive difficulties in quantum physics, and so the CI was duly

¹²⁸Cushing, "Copenhagen Hegemony," 96.

¹²⁹Cassidy, "Heisenberg," 112.

¹³⁰Beller, *Quantum Dialogue*, 172.

noted, in some cases accepted, but in most cases uncelebrated when bright minds came lecturing from Europe in the 1920s and 30s. As for American physicists traveling abroad, Cushing notes that without exception they went to laboratories that were affiliated with the Copenhagen doctrine.¹³¹ The general disinterest among the Americans for mixing physics and philosophy as well as the disregard for alternatives to the standard interpretation helped ensure that the CI would be well established as *the* interpretation of quantum physics by the close of the 1920s.

Things might have been different, however. The empirical equivalence between the CI and such alternative views as Bohm's indicates that non-science factors led to the dominance of the CI. If those non-science factors had been different, most likely the CI would have passed from the scene without much notice. Cushing addresses this possibility and says the dominant interpretation might be "diametrically opposed to what it is now" if historical contingencies had played out differently.¹³² For instance, Cushing believes that if Bohm's theory had preceded Bohr's out of the gate, Bohm would have carried the day on the strength of his empirically fit resources.¹³³ I believe this claim is plausible *if* Bohm's view had come before Bohr's and generated enough interest among American physicists to rebut the Central European fascination with acausality and irrationality. The CI dominates quantum physics, but it could have and *should* have been different.

Von Neumann's Proof

John von Neumann ensured that the CI would not lose its early momentum among physicists and philosophers with the introduction in 1932 of his proof against the possibility of hidden variables in quantum physics. Frederick J. Belinfante says von

¹³¹Cushing, *Quantum Mechanics*, 122.

¹³²Cushing, "Underdetermination," 276.

¹³³Cushing, "Copenhagen Hegemony," 97.

Neumann's proof was taken to be the gospel truth, a fact that forbade any progress in the search for hidden variables, and hence forestalled the development of an alternative to the CI.¹³⁴ Philosopher Grete Hermann showed in 1935 that the proof was completely impotent, but no one took note of this and the proof went without additional challenge for twenty years.¹³⁵ In 1966, John Bell joined Hermann in calling the von Neumann proof a failure.¹³⁶ Pinch explains Bell's work helpfully.

[Bell] showed that one of the axioms adopted by von Neumann in his proof implicitly ruled out hidden variables. Thus it turned out that all that von Neumann had done was to show that hidden variables as defined by him were impossible. Von Neumann's mathematical reasoning was correct but he had overgeneralised from one particular class of hidden-variables theory (and not a very likely one) to all such theories.¹³⁷

It is particularly important to note that the "one particular class of hidden-variables theory" that von Neumann does successfully rule out does *not* include that which is suggested by Bohm.¹³⁸ Bohm is free and clear of von Neumann's proof, but it was decades before this fact was handed on to the majority of quantum theoreticians. Thus, those who contended that von Neumann had refuted Bohm's interpretation did so without seriously consulting either von Neumann or Bohm. Pinch believes physicists were simply repeating uncritically the official-history rendering that had been passed on to them.¹³⁹ In other words, student-physicists heard in the lecture hall that some fellow named von Neumann had unseated any and all possibilities of hidden variables in quantum mechanics, and so all one needed to do was cite the famed von Neumann anytime

¹³⁴Frederick J. Belinfante, *A Survey of Hidden-Variables Theories*, vol. 55 of *International Series of Monographs in Natural Philosophy*, ed. D. Ter Haar (New York: Pergamon Press, 1973), 24, 34.

¹³⁵Pinch, "What Do Proofs Do?" 185-86.

¹³⁶Says Bell, "It was not the objective measurable prediction of quantum mechanics which ruled out hidden variables. It was the arbitrary assumption of a particular (and impossible) relation between the results of incompatible measurements either of which *might* be made on a given occasion but only one of which can in fact be made." John Bell, "On the Problem of Hidden Variables in Quantum Mechanics," in *Speakable and Unsayable in Quantum Mechanics: Collected Papers on Quantum Philosophy*, 2nd ed. (Cambridge: Cambridge University Press, 2004), 5.

¹³⁷Pinch, "The Hidden-Variables Controversy," 51.

¹³⁸Cushing, *Quantum Mechanics*, 134.

¹³⁹Pinch, "What Does a Proof Do?" 187.

hidden variables were mentioned. It did not matter to them that they had no personal familiarity with von Neumann's argument. It was sufficient to know that von Neumann's contemporaries had hailed the proof as valid and true and had silenced all comers by its incantation.¹⁴⁰

In summary, the consensus opinion among contemporary commentators is that von Neumann's proof was not valid against any reasonable variety of hidden-variables theory, and that this lack of validity should have been noted upon inspection. Indeed, it is difficult to see why anyone ever took the proof so seriously.¹⁴¹ Difficult, that is, unless you take into consideration the roles philosophy, sociology, and historical contingency played in the establishment of the Copenhagen hegemony.

Scientific Critique of the Orthodox Interpretation

As demonstrated above, it seems likely that the founders of the CI drafted their work in such a way as intentionally to reflect major philosophical and societal fashions current to post-war Germany. After all, these men had adopted these very fashions as their own. This calls into question the CI's suitability as a scientific interpretation for the obvious reason that the Copenhagen group may have been predisposed to seize upon the appearance of paradox, acausality, and irrationality in quantum theory and mark these down for ontological instantiation.

The CI is also objectionable on more strictly scientific grounds. I discuss several of these below and conclude that these represent yet another reason interpreters of quantum-physical theory are justified to withhold assent from the most popular interpretation in the history of quantum physics.

¹⁴⁰Feyerabend says mere mention of the proof settled disputes like magic. Feyerabend, *Killing Time*, 77-78.

¹⁴¹Belinfante, *A Survey*, 34.

Problems of Demarcation and Measurement

The demarcation problem has been mentioned several times above and can be explained by the following question: how are we to divide the world into “speakable” macro-systems and unspeakable quantum systems?¹⁴² In other words, if according to the standard interpretation quantum systems are non-classical, acausal, and possibly non-existent apart from observation, how do we demarcate them from macroscopic systems that are classical, causal, and clearly existent apart from observation? How many atoms must cohere before a quantum system “converts” to a classical system? Jeffrey Bub gives articulate expression to how this problem relates to the act of measurement as conceived by the CI.

For Bohr, quantum systems manifest their properties under experimental conditions defined by classical concepts. Change the conditions over here, and you modify the properties of quantum systems over there, not via a ‘mechanical disturbance’ of the system but merely in virtue of the fact that a quantum system *has no properties except* in the context of a specific (experimental) macroenvironment that is described in terms of the concepts of classical physics. This conception shatters the unity of classical physics, because we can no longer conceive of the macrosystems that are our measuring instruments as mere aggregates of Microsystems, for *these* systems have no properties except in the context of a super-macro-environment. How macrosystems, considered as many-body Microsystems in quantum mechanics, ever come to have (classical) properties is a mystery in the Copenhagen interpretation.¹⁴³

Indeed, if quantum systems are genuinely acausal and non-classical, how can the addition of more quantum entities convert them to classically described macrosystems? Or, as CI enthusiast John Wheeler expresses it, “When does probability give way to actuality?”¹⁴⁴ Or again, as many-worlds advocate David Papineau puts it, how big does the measuring apparatus have to be before it qualifies as a macro-system and hence

¹⁴²John Bell, “Speakable and Unspeakable in Quantum Mechanics,” in *Speakable and Unspeakable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 171.

¹⁴³Jeffrey Bub, “How to Kill Schrödinger’s Cat,” in *The World View of Contemporary Physics: Does It Need a New Metaphysics?* ed. Richard F. Kitchener (Albany: State University of New York Press, 1988), 69.

¹⁴⁴John Archibald Wheeler and Kenneth Ford, *Geons, Black Holes, and Quantum Foam: A Life in Physics* (New York: W. W. Norton & Company, 1998), 269.

becomes capable of collapsing the wave-function of the quantum system?¹⁴⁵ Alternatives to the CI do not suffer this problem because they do not posit that the quantum world is radically different from classical systems. They grant that we are presently saddled with quantum paradoxes but claim that these are a reflection of our investigative and theoretical limitations, limitations that may be lifted with future discoveries and advancements. Bohm and Hiley, for instance, suggest that the demarcation problem is solved if we simply break from the CI and grant that quantum systems have concrete reality apart from observation. They call their model the quantum-potential interpretation, and explain it as follows.

[In] the quantum-potential interpretation, . . . microreality, in the usual sense of the word, is assumed from the outset. . . . In this approach, individual quantum systems are taken to be real, independent of all discussion of measuring apparatus and of preparation of the quantum state. Moreover, because all levels are thus assumed to be real, there is an unbroken approach to the classical limit, which arises in a very simple and direct way wherever this quantum potential can be neglected.¹⁴⁶

Realist proposals such as this assume that, in principle, it is possible to speak of a sort of continuum from micro to macro. This need not entail strict bottom-up causality. It only means that such concepts as causality and observer-independent existence are qualities that befit both quantum- and non-quantum systems, whether or not our current investigative prowess enables us to demonstrate this fact satisfactorily.

Violation of the Correspondence Principle

Heinz Post describes the General Correspondence Principle as “the requirement that any acceptable new theory *L* should account for the success of its predecessor *S* by ‘degenerating’ into that theory under those conditions [by] which *S* has been well con-

¹⁴⁵David Papineau, *The Roots of Reason: Philosophical Essays on Rationality, Evolution and Probability* (Oxford: Clarendon Press, 2003), 225.

¹⁴⁶David Bohm and B. J. Hiley, “Unbroken Quantum Realism, from Microscopic to Macroscopic Levels,” *Physical Review Letters* 55 (1985): 2511.

firmed by tests.”¹⁴⁷ Norris gives a clear example of how this principle is obeyed by even the most revolutionary of theories.

The classic case here is of course that of Einstein’s special and general relativity, interpreted *not* as a full-scale replacement for Newtonian theories of space, time, and gravitation, but rather as a more comprehensive unified account which conserved Newton’s theory as a special-case instance valid for all space-time frameworks whose gravitational fields were weak and where maximal velocities were nowhere near the speed of light. Thus Einstein’s hypothesis respected the standard constraint, i.e. that ‘a theory that supersedes a previous one whose domain of validity has been established must reduce to the old one in a suitable limit’.¹⁴⁸

Using Heinz’s terminology from above, Einstein’s new theory *L* embodied significantly the lower-level theoretical structure of Newton’s physics, *S*, which fact explains how *S* is successful even though *L* now displaces it.¹⁴⁹ Heinz believes this principle indicates that, contra Kuhn, even the most radical of scientific revolutions do not necessarily represent the loss of previously touted explanatory power nor the complete rejection of previous theories.¹⁵⁰ Rather, the new theories retain lower elements of the theories they succeed and by virtue of this fact preserve their explanatory power. That the received version of quantum mechanics *fails* to preserve elements of classical physics is, for Post, an indication that it is a mistaken enterprise and that a new *L* theory is needed, one that successfully incorporates the past and current successes of Newtonian physics.¹⁵¹

Cushing agrees that the CI does not satisfy the requirements of the Correspondence Principle, whereas Bohm’s does. However, he wonders if the fact that Bohm has been rejected in favor of the correspondence-failing CI is an indication that the Corre-

¹⁴⁷Heinz R. Post, “Correspondence, Invariance and Heuristics: In Praise of Conservative Induction,” in *Correspondence, Invariance and Heuristics: Essays in Honour of Heinz Post*, ed. Steven French and Harmke Kamminga (Boston: Kluwer Academic Publishers, 1993), 16.

¹⁴⁸Norris, *Quantum Theory*, 76.

¹⁴⁹“The General Correspondence Principle not only demands agreement of the *L*-theory with the *S*-theory in singular statements relating to certain events, but claims that any *L*-theory will in fact embody a good deal of the (lower) theoretical structure of the *S*-theory. Only in this way is the success of *S* explained.” Post, “Correspondence,” 17.

¹⁵⁰*Ibid.*, 26.

¹⁵¹*Ibid.*, 22.

spondence Principle is not an important guide for theory selection. The best that can be said, concludes Cushing, is that theory construction generally is conservative in the manner suggested by the Correspondence Principle.¹⁵² Hence, Cushing takes the principle to be descriptive rather than prescriptive.

It is clear that the Correspondence Principle is shattered by the standard interpretation of quantum mechanics, a fact well illustrated by such problems as those of demarcation and measurement discussed above. If one takes the Correspondence Principle to be prescriptive, the CI is ruled out as a viable interpretation for quantum physics. If, on the other hand, the principle is merely regarded as a description of how theory selection *typically* unfolds, we will be unable definitively to overturn the CI based on its radical non-correspondence with classical physics. Nevertheless, even where the Correspondence Principle is thought to be merely descriptive, the CI's failure to preserve classical physics as a limit case can be regarded as so spectacular an exception to the norm that we may still cite the Correspondence Principle as a key line of evidence against the propriety of the Copenhagen hegemony.

The Completeness Claim

One of the more significant components of the CI is the claim that the quantum theory as described eighty years ago is complete, such that no paradox-erasing supplementation is possible. This is a favorite target of realists writing from the science and philosophy perspectives. Karl Popper says the completeness claim is an “outrageous” science stopper.¹⁵³ Michael Redhead notes that Bohr's completeness claim, if taken as law, prohibits investigators from asking important questions and sets “dogmatic limitations” on theorizing, all on the basis of “obscure philosophical preconceptions”¹⁵⁴ De

¹⁵²Cushing, *Quantum Mechanics*, 6.

¹⁵³Karl Popper, *Quantum Theory and the Schism in Physics* (London: Routledge, 1982), 5-6.

¹⁵⁴Michael Redhead, *Incompleteness, Nonlocality, and Realism: A Prolegomenon to the Philosophy of Quantum Mechanics* (Oxford: Clarendon Press, 1987), 51.

Brogie indicates that the completeness claim is contrary to lessons learned from the history of science.

To try to stop all attempts to pass beyond the present viewpoint of quantum physics could be very dangerous for the progress of science and would furthermore be contrary to the lessons we may learn from the history of science. This [history] teaches us, in effect, that the actual state of our knowledge is always provisional and that there must be, beyond what is actually known, immense new regions to discover.¹⁵⁵

Dipankar Home points out that the completeness claim is of a piece with the positivist view that science is concerned only with results that are empirically testable.¹⁵⁶ Ironically, this comes back to haunt the CI in the following way.

It is important to note that the standard interpretation hinges on an assumption that *cannot be experimentally verified*: A wave function is assumed to offer the most complete possible description of the state of an individual system. Thus we are prima facie entitled to investigate whether the wave function description can be supplemented by additional variables (commonly referred to as hidden variables) to imagine individual systems that are described by the same wave function but differ in those additional parameters.¹⁵⁷

If the completeness claim cannot be empirically verified, the positivism that courses through the center of the CI supplies the very evidence needed to refute both the completeness claim and the CI generally.

Cosmologist Dennis Sciama once said that the standard of argumentation for the interpretation of quantum physics is zero.¹⁵⁸ This is particularly true for the oft repeated claim that quantum theory is complete.

Hidden Variables and Indeterminism

Einstein spoke for realists of his day and ours when he said that the statistical character of quantum theory indicates one thing only: quantum theory is an incomplete

¹⁵⁵Bohm, *Causality and Chance*, x.

¹⁵⁶Dipankar Home, *Conceptual Foundations of Quantum Physics: An Overview from Modern Perspectives* (New York: Plenum Press, 1997), 16.

¹⁵⁷Ibid., 23, emphasis mine.

¹⁵⁸David Deutsch, *The Fabric of Reality: The Science of Parallel Universes—and Its Implications* (New York: Penguin, 1997), 335.

description of quantum physical reality.¹⁵⁹ The history of science seems to back Einstein's confidence, for scientists have often appealed to the hidden-variables theme when confronted with such difficulties. As Jammer says, the idea of hidden variables is as old as physical science itself.

The earliest theory of hidden variables which by their very definition are undetectable by direct observation and which, moreover, were characterized by mathematical (geometric) properties was probably the theory of vision in terms of 'optical rays' (radii) proposed by Archytas of Tarentum in the first half of the fourth century BC.¹⁶⁰

Historically, the most significant motivation for positing hidden variables is the belief that action-at-a-distance is impossible. Ernan McMullin notes that this conviction dates back to at least as far as Aristotle, who said all action is either self-motion or contact action.¹⁶¹ Aquinas agreed with Aristotle and argued that not even God can act at a distance. Rather, all things are immediate to God, and so God acts on them in a way analogous to contact action.¹⁶² The presupposition that distant action is impossible became particularly important when scientists began to grapple with the phenomenon of gravity. Isaac Newton and René Descartes, for instance, both insisted that gravity could not act if space is a vacuum, yet Newton was dissatisfied with contact action as limited by standard mechanical conceptions.¹⁶³ Space, therefore, must be filled with ether that supports the possibility of some variety of contact action between ostensibly separated causes and effects.

After the *Principia*, there were basically two camps on the 'gravity dilemma.' The one, among whose members were the Cartesians, Leibniz, and Huygens, maintained that an ether was required to allow any intelligible explanation of gravitational phe-

¹⁵⁹ Albert Einstein, "Reply to Criticisms," in *Albert Einstein: Philosopher-Scientist* (New York: Tudor, 1951), 666.

¹⁶⁰ Jammer, *The Philosophy of Quantum Mechanics*, 257.

¹⁶¹ Ernan McMullin, "The Explanation of Distant Action: Historical Notes," in *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*, ed. James T. Cushing and Ernan McMullin (Notre Dame: University of Notre Dame Press, 1989), 275.

¹⁶² *Ibid.*, 277.

¹⁶³ *Ibid.*, 287.

nomena. The other, notably represented by Newton's ally, the cleric Samuel Clarke, took gravity to be evidence for God's action. Even though something cannot act where it is not, God is everywhere and, hence, 'instantaneous' action between spatially separated bodies is no mystery.¹⁶⁴

Newton was not able to come to a satisfactory conclusion about what sort of intermediary agency existed between widely separated heavenly bodies, but he was steadfastly against distant action and maintained faith that a future stage of inquiry would uncover definitive information validating contact action.¹⁶⁵ In other words, Newton was holding out hope on the basis of hidden variables. It is well he did so, for Einstein would eventually supply to Newton's theory of universal gravitation the content that many feel is adequate to explain gravity in terms of local interactions.¹⁶⁶ As Moreland explains, the gravitational force is now thought by many scientists to be the effect of particles called gravitons that transmit between the heavenly bodies.¹⁶⁷ Naturally, if everyone from Newton forward had assumed that hidden variables were impossible, the search for deeper understanding would have halted long before Einstein started us on the road to explaining gravity as a local phenomenon.

Einstein also helped unveil hidden variables operative in another troublesome phenomenon, that of Brownian motion. George Musser explains that Einstein successfully described the jiggling of dust motes, which for quite a time was thought to be random, as the effect of unseen molecules that actually followed classical causal laws.¹⁶⁸ It is only the aggregation of a great many of such law-abiding molecules that creates a frenzy of collision and ricochet that appears genuinely random.¹⁶⁹ So again, we have an example

¹⁶⁴Cushing, *Quantum Mechanics*, 19.

¹⁶⁵McMullin, "The Explanation," 291.

¹⁶⁶Cushing, *Quantum Mechanics*, 18.

¹⁶⁷Moreland, *Christianity*, 54.

¹⁶⁸George Musser, "Was Einstein Right?" *Scientific American* 291 (September 2004): 89.

¹⁶⁹Pinch, "The Hidden-Variables Controversy," 48. See also John Bell, "Introduction to the Hidden-Variable Question," in *Speakable and Unspeakable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 30.

from the history of science that demonstrates that what was once thought to be genuinely random was subsequently described causally once hidden variables were discerned.

Carl Benedicks has noted that in seventy-four of the seventy-five generations that had possession of some form of atomic theory, a pessimistic view with regard to hidden variables could have sunk into deep mire the whole quest for more adequate understanding. He goes on to say that the CI has done just this, converting mere difficulties into insurmountable barriers to progress.¹⁷⁰ Peter Holland says science simply would not exist if ideas were admitted roles in theory construction only on the condition that they had firm empirical backing.¹⁷¹ In fact, he says, one can never prove that a theory is absolutely complete, which is another way of saying one can never rule out the possibility that hidden variables may lurk below the cognizance of researchers of any era, no matter how advanced their understanding may be.

Importantly, interest in the possibility of hidden variables for quantum physics has grown significantly in the past few years. Musser traces this mostly to the work of Gerard't Hooft of the University of Utrecht.

He argues that the salient difference between quantum and classical mechanics is information loss. A classical system contains more information than a quantum one does, because classical variables can take on any value, whereas quantum ones are discrete. So for a classical system to give rise to a quantum one, it must lose information. And that can happen naturally because of friction or other dissipative forces. If you throw two pennies off the Empire State Building at different speeds, air friction causes them to approach the same terminal velocity. A person standing on the sidewalk below can scarcely tell the precise velocity at which you threw the pennies; that information is a hidden variable. . . . Therefore, nature could be classical at its most detailed level yet look quantum-mechanical because of dissipation.¹⁷²

This seems to be a promising avenue for the pursuit of hidden variables, one that realists will likely work hard to develop further. It is not clear, however, that this sort of hidden-variables approach can save locality. If it cannot, and *if* experiments that ap-

¹⁷⁰Heilbron, "The Earliest Missionaries," 219.

¹⁷¹Peter R. Holland, *The Quantum Theory of Motion: An Account of the de Broglie-Bohm Causal Interpretation of Quantum Mechanics* (Cambridge: Cambridge University Press, 1993), 25.

¹⁷²Musser, "Was Einstein Right?" 90.

pear to bear out Bell's Theorem stand the test of time, we may be forced to say that hidden variables are non-local, but this still saves causality, albeit in a new form, and is thus a far better concession than giving up on hidden variables and causality altogether.

Quantum Non-Locality

Proponents of the CI generally emphasize non-locality as an interpretive key to unlocking the many non-classical metaphysical implications of quantum physics, the chief of which is the apparent inapplicability of the principle of causality. After all, say Copenhagen theorists, if two quantum entities are "entangled" even though they are separated by a distance too vast to span by the fastest physical means possible—the speed of light—it seems that influence is propagated non-physically, non-locally, and therefore non-causally. However, significant interpreters of the quantum non-locality phenomenon reject this conclusion.¹⁷³ For instance, Tim Maudlin argues that quantum entanglement can be explained via superluminal causal connections that do not involve matter or energy transport.¹⁷⁴ Maudlin's suggestion rests on the feasibility of suggesting that non-local hidden variables exist, such that some variety of non-local causal influence saves the principle of causality. Shimony observes that this would exorcise both quantum entanglement and quantum indeterminism from quantum theory, but worries that it may be difficult to devise a formulation for non-local causality that does not violate the principles of Einstein's relativity theories.¹⁷⁵ Shimony is correct in both assertions—accepting non-locality and giving it a causal interpretation does much to remove the controversial elements of the CI, but doing so may present contradiction with Einstein's insistence that

¹⁷³Raymond Y. Chiao, Paul G. Kwiat, and Aephraim M. Steinberg, "Faster than Light?" *Scientific American* 269 (August 1993): 53-54; Alain Aspect, "Introduction: John Bell and the Second Quantum Revolution," in *Speakable and Unspeakable in Quantum Mechanics: Collected Papers on Quantum Philosophy* (Cambridge: Cambridge University Press, 2004), xxvi.

¹⁷⁴Tim Maudlin, *Quantum Non-Locality and Relativity: Metaphysical Intimations of Modern Physics*, 2nd ed. (Oxford: Blackwell, 2002), 240.

¹⁷⁵Abner Shimony, "Search for a Worldview Which Can Accommodate Our Knowledge of Microphysics," in *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*, ed. James T. Cushing and Ernan McMullin (Notre Dame: University of Notre Dame Press, 1989), 30.

communications cannot be conveyed faster than the speed of light. However, the conflict with Einstein's assertion is formidable only if one assumes that Einstein has given the full and final word on the possibility of superluminal transfer. Perhaps Maudlin is correct to suggest that while energy and matter cannot convey faster than light influences, there may nevertheless be some unknown variety of medium by which such signals can be conveyed. One thinks of the former ether theories in this context. Can these be resurrected? At present, the suggestions put forth by Maudlin and others are nothing more than speculation. Perhaps even on the most optimistic reading their offerings simply fall short. However, we may still be optimistic that their efforts are early signals of a coming sea change. As history demonstrates, when theorists are unfettered in their speculations, remarkable insights often follow. The more theorists turn aside from the CI's completeness claim, the more energy will be added to the speculative pursuit of better answers to the non-locality problem in quantum physics.

Another indication that non-locality is not all it is advertised to be is that the non-locality condition can safely be ignored for macro-objects. As Linda Wessels notes, scientists can carry on treating everyday objects in a classical fashion, meaning they have objective properties and that they obey the principle of causality.¹⁷⁶ Finally, as noted in chapter 4, accounts of non-locality that include claims that the whole universe is entangled as far back as the Big Bang are greatly exaggerated. The fact is any given real-world instance of entanglement is short-lived and essentially local, for entangled particles are very soon cut away from one another's causal influence by virtue of the fact that each particle is constantly bombarded with other quantum objects, such that new entanglements are formed and disbanded moment by moment.¹⁷⁷ Thus, whatever may prove to be

¹⁷⁶Linda Wessels, "The Way the World Isn't: What the Bell Theorems Force Us to Give up," in *Philosophical Consequences of Quantum Theory: Reflections on Bell's Theorem*, ed. James T. Cushing and Ernan McMullin (Notre Dame: University of Notre Dame Press, 1989), 95-96.

¹⁷⁷Greene, *Fabric*, 122-23; Arthur Zajonc, *The New Physics and Cosmology: Dialogues with the Dalai Lama* (Oxford: Oxford University Press, 2004), 28.

the truth about quantum non-locality, Copenhagen tales of a holistic, entangled world are simply overblown.

In Defense of Realism

Positivism and anti-realism play significant roles in the CI. For instance, Bohm and Hiley identify positivism as the motive behind Bohr's conclusion that the current unpredictability of quantum events is an indication that the quantum state of being is inherently ambiguous.¹⁷⁸ At most, the CI seems intent on "saving the phenomena" while showing little if any regard for explanatory power. According to McMullin, this approach has been considered inadequate at least as far back as Aristotle.¹⁷⁹ There must be a "why," a causal explanation of phenomena, if phenomena are truly to come under the aegis of scientific description. In this light, quantum theory is clearly incomplete, especially in its Copenhagen formulation. Realist Michael DeVitt commends an instrumentalist approach to quantum physics because, as he says, "quantum theory is not to be trusted at this stage as a guide to reality."¹⁸⁰ Paul Davies and J. R. Brown take a similar approach. They classify quantum theory as a "temporary expedient" that will be overturned by future experiments that will expose points on which the current theory is simply wrong.¹⁸¹

Realism includes the beliefs that the world has a definite, mind-independent existence, and that causal factors are extant and operative in physical systems whether or not our current science detects them. In the event that scientists discover elements of reality that we cannot readily understand, as is the case in current quantum science, the realist regards it as "unnecessary arrogance" to suppose that the limitations and uncertainties we

¹⁷⁸David Bohm and B. J. Hiley, *The Undivided Universe: An Ontological Interpretation of Quantum Theory* (New York: Routledge, 1993), 24.

¹⁷⁹McMullin, "Explanation," 275.

¹⁸⁰Michael DeVitt, *Realism and Truth*, 2nd ed. (Princeton: Princeton University Press, 1991), 132.

¹⁸¹J. R. Brown and P. C. W. Davies, *The Ghost in the Atom: A Discussion of the Mysteries of Quantum Physics* (Cambridge: Cambridge University Press, 1986), 51-52.

experience inhere the real world itself.¹⁸² This realist assessment of quantum theory is increasingly popular, for, as Stathis Psillos has noted, realism is going through a renaissance period after a long season of neglect.¹⁸³

However, thoroughgoing realism with regard to quantum physics is simply not possible given the current state of the science. The best stance seems to be realism with respect to science generally, but qualified instrumentalism with respect to quantum physics specifically. Norris expresses this approach, which is similar to DeVitt's above, in the following way.

At this stage the best (most rational) attitude for physicists and philosophers to adopt is one of qualified instrumentalism, or a willingness to work with the theory as it stands while acknowledging its limits and keeping an open mind with respect to alternative accounts – such as Bohm's – that hold out the prospect of a fuller, more complete understanding.¹⁸⁴

In this approach, the fruitfulness of quantum theory is preserved by the *pro tempore* instrumentalist approach while the rationality of nature is preserved by the acknowledgment that realism is a genuine future possibility for quantum science and quantum philosophy. In other words, we acknowledge that our current theory is inadequate rather than claim that nature is actually as bizarre as that theory says.¹⁸⁵

Einstein once described the CI as a “tranquilizing philosophy—or religion?— [that] is so delicately contrived that, for the time being, it provides a gentle pillow for the true believer from which he cannot very easily be aroused.”¹⁸⁶ Similarly, Gell-Mann has claimed that, so far as the description of quantum reality is concerned, Niels Bohr brainwashed an entire generation of physicists into thinking that the CI had settled the issue

¹⁸²Euan Squires, *The Mystery of the Quantum World* (Boston: Adam Hilger, Ltd., 1986), 132.

¹⁸³Stathis Psillos, “The Present State of the Scientific Realism Debate,” in *Philosophy of Science Today*, ed. Peter Clark and Katherine Hawley (Oxford: Oxford University Press, 2003), 60.

¹⁸⁴Norris, *Quantum Theory*, 35.

¹⁸⁵Rachel Wallace Garden, *Modern Logic and Quantum Mechanics* (Bristol: Adam Hilger Ltd, 1984), 177.

¹⁸⁶Einstein cited in K. Przibram, *Letters on Wave Mechanics* (New York: Philosophical Library, 1967), 31.

forever.¹⁸⁷ Popper calls the profundity of the formulae associated with the CI the “road to perdition,” while Bell characterizes current quantum theory as “unprofessionally vague and ambiguous.”¹⁸⁸

Dozens of significant philosophers and physicists agree with the sentiments expressed by Einstein, Gell-Mann, Popper, and Bell. Aspect notes that Bell’s work in particular has helped physicists to see that the conceptual development of quantum physics was not completed by the work of the Copenhagen theorists.¹⁸⁹ The quantum world is largely untapped, at least so far as its interpretation is concerned, and possibly the formalism itself is due for overhaul. As physicists and philosophers continue to break away from the pack and think independently as they examine the numerous scientific considerations cited above, it seems likely that the CI will give way someday to a realist construal that provides a more classical description of quantum physics.

Christian Worldview Critique of the Copenhagen View

We have seen important philosophical and scientific indications that the CI is not an inviolable interpretation of quantum physics. In fact, on both counts the CI is not only questionable, but objectionable. In this last section, I discuss several evidences that the CI is also objectionable from the standpoint of the Christian worldview due to the fact that the CI either makes or is the basis for several claims about the world that are contrary to fundamental elements of the Christian faith.

To begin with, note that the CI instantiates an insuperable truth problem. Zohar, Born, and others cited above spoke of how belief in transcendent, ultimate, or exclusive truth is harmful, and how developments in quantum physics have shown a better way, namely, the adoption of the complementarity doctrine to solve the problem that

¹⁸⁷Gell-Mann cited in Nick Herbert, *Quantum Reality: Beyond the New Physics* (Garden City, NY: Anchor Press, 1985), 45.

¹⁸⁸Popper, *Quantum Theory*, 157; Bell, “Beables,” 173.

¹⁸⁹Aspect, “Introduction,” xix.

arises when truth claims conflict with one another. Menas Kafatos and Robert Nadeau express quantum epistemology and its worldview implications in a particularly revealing manner.

The new epistemology of quantum theory reveals that fundamental oppositions disclosing the profound truths of nature are complementary, and those constructs have consistently brought us closer to a vision of nature which belies both classical ontological dualism and the bias that ultimate truths are transcendent and pre-existing.¹⁹⁰

Recall also the earlier citation from Kafatos and Nadeau in which they specifically state that quantum physics reveals a holistic ontology that is contrary to the dualism associated with the Christian worldview.¹⁹¹ The concepts of holism and complementarity present conflict with the Christian worldview in the following ways. First, the denial that truth can be ultimate and transcendent is clearly contrary to the Biblical claim that God, who is transcendent, *is* truth and has *revealed* truth by words and actions. Ronald Nash points out that the Bible teaches the reality of objective truth in several ways, including by presupposition. For instance, the apostle Paul's argument in 1 Corinthians 15 about the resurrection of the dead presupposes the reality of objective truth.¹⁹² Furthermore, the whole tenor of the gospel as presented by Christ himself necessitates an objective, exclusivist model of truth. "I am the way, the truth, and the life," Jesus said, "no one comes to the Father except through me" (John 14:6). In John 8:24, Jesus indicates that the contrary to believing in him, namely, *not* believing in him, leaves one dead in sin: "Unless you believe that I am He, you will die in your sins." Here we see that Bohr's complementarity doctrine, which states that the opposite of a profound truth is another profound truth, simply does not carry over to a Christian construal of the world, nor does Born's and Zohar's assertion that belief in exclusivist monotheistic religion is a root of moral evil, and

¹⁹⁰Menas Kafatos and Robert Nadeau, *The Conscious Universe: Part and Whole in Modern Physical Theory* (New York: Springer-Verlag, 1990), 117.

¹⁹¹*Ibid.*, 75.

¹⁹²Ronald H. Nash, *Life's Ultimate Questions: An Introduction to Philosophy* (Grand Rapids: Zondervan, 1999), 248.

that quantum physics overturns such belief systems.¹⁹³

The majority of Christian thinkers have been realists with respect to the external world and the philosophy of science.¹⁹⁴ It is also the majority view among those who offer commentary on the relations between science and the Christian worldview.¹⁹⁵ The chief reason this is so stems from the Biblical doctrine of creation, which entails that the human mind is created in such a way as to match the intelligibility of nature.¹⁹⁶ The “sameness” between mind and nature, and the intelligibility of each, are secured by the fact that both are made by God to reflect his rationality. The human mind in particular is readymade for knowledge of truth. “Human knowledge can be regarded as a reflection of the truth originating in the mind of God. To be more specific, God has endowed humans with a structure of rationality patterned after the divine ideas in His own mind: we can know truth because God has made us like Himself.”¹⁹⁷ As Del Ratzsch puts it, Christians believe that God created both the world and humans, and that humans were crafted in such a way as to be “knowing beings” in this tailor-made world.¹⁹⁸

The realism position is bound up with the correspondence view of truth, which is also a component of the Christian worldview.¹⁹⁹ Though commentators do not typically

¹⁹³Max Born, *Physics in My Generation*, 2nd ed. (New York: Springer-Verlag, 1969), 143; Danah Zohar and Ian Marshall, *The Quantum Society: Mind, Physics, and a New Social Vision* (New York: Quill, 1994), 141.

¹⁹⁴Dana Edgar Bible, “Metaphysical Implications of the New Physics: An Assessment of Christian and Non-Christian Views” (Ph.D. diss., Southwestern Baptist Theological Seminary, 1986), 116; William E. Brown, “Quantum Theology: Christianity and the New Physics” (paper presented at the annual meeting of the Evangelical Theological Society, Portland, OR, March 1988), 7.

¹⁹⁵Moreland, *Christianity*, 141.

¹⁹⁶John Hedley Brooke, *Science and Religion: Some Historical Perspectives* (Cambridge: Cambridge University Press, 1991), 19.

¹⁹⁷Ronald H. Nash, *The Word of God and the Mind of Man: The Crisis of Revealed Truth in Contemporary Theology* (Phillipsburg, NJ: P&R Publishing, 1982), 81. See also, Steven Wellum, “Post-conservatism, Biblical Authority, and Recent Proposals for Re-Doing Evangelical Theology: A Critical Analysis,” in *Reclaiming the Center: Confronting Evangelical Accommodation in Postmodern Times*, ed. Millard J. Erickson, Paul Kjoss Helseth, and Justin Taylor (Wheaton, IL: Crossway Books, 2004), 187.

¹⁹⁸Del Ratzsch, *Science and Its Limits: The Natural Sciences in Christian Perspective* (Downers Grove, IL: InterVarsity Press, 2000), 138.

¹⁹⁹Douglas Groothuis, “Truth Defined and Defended,” in *Reclaiming the Center: Confronting Evangelical Accommodation in Postmodern Times*, ed. Millard J. Erickson, Paul Kjoss Helseth, and Justin Taylor (Wheaton, IL: Crossway Books, 2004), 68-69.

address this issue directly, the CI clearly denies the very possibility of the correspondence theory of truth, at least as relates to quantum systems, and possibly to macro-systems as well. Reality “out there” is created by acts of observation that are made or directed by humans. In the more extreme expressions of the CI’s measurement doctrine noted above, physicists and philosophers go so far as to say that our observations create past truth, even the very existence of the universe. This undermines the Christian belief that God is the author of the world, and that our knowledge is true knowledge only insofar as it corresponds with reality (and history) as God has made it.

Stanley Jaki has said that science is not merely an objective tool, but intellectual creativity. As such, the scientific endeavor is closely joined to presuppositions and ideologies.²⁰⁰ Importantly, the conflict between the CI and the Christian worldview recalls the ideological support Christian theism lent to science in the early stages of the development of science. For instance, the presupposition that nature is stable and rational is necessary if science is to be possible. Historically, this ideology came from the Christian Bible, which teaches that stable, rational nature is a reflection of its stable, rational Creator.²⁰¹ Furthermore, the fact that creation was thought to be the product of a rational Designer encouraged empirical investigation of the natural realm. Ratzsch expresses this issue helpfully.

Christians saw the world as a creation (thus orderly and uniform) of a Person (thus rational) who had created freely (thus requiring empirical investigation) unconstrained by our prejudices and expectations (thus requiring open-minded investigation). So the basic character of science grew to be what one could expect from a Christian outlook.²⁰²

Vern Poythress describes natural law as the imperfect human description of the very regularities of God’s own providential care for his creation.²⁰³ From this it follows

²⁰⁰Stanley L. Jaki, *The Savior of Science* (Grand Rapids: Eerdmans, 2000), 1.

²⁰¹*Ibid.*, 65.

²⁰²Ratzsch, *Science*, 136-37.

²⁰³Vern S. Poythress, “Why Scientists Must Believe in God: Divine Attributes of Scientific Law,” *Journal of the Evangelical Theological Society* 46 (2003): 112.

that the natural order will operate rationally as a reflection of God's nature. This is not to say that humans will always be able to detect said rationality. Certainly, God's actions in the natural order may in some cases be beyond our comprehension, but this is not to say that such actions are fundamentally irrational. In quantum mechanics, for instance, God's ordering of quantum phenomena may be beyond our understanding due to our inability precisely to penetrate the quantum scale. In principle, however, all natural operations ought to be considered rational, orderly, a reflection of God their Maker.

The CI undermines confidence in the in-built rationality of the physical universe by declaring that microphysical entities are lawless, causeless, indeterminate, and thus irrational. In this regard, the CI closely matches controlling presuppositions in historical Hindu and Chinese ideologies, presuppositions that kept the East from seeing the world as a rational expression of a rational Maker, and hence ensured that science would arise in the Christian West or nowhere at all.²⁰⁴ In contrast to the non-Christian peoples of the world, Christians believed science could be done and in fact *should* be done.²⁰⁵

As we saw in chapter 4, some Christian interpreters view the CI's emphasis on quantum indeterminism as an evidence for God's action. Dana Bible, for instance, says "Ultimate indeterminacy is the conclusion that, 'it is determined that nothing can be determined,'" which is a pointer to transcendence, an "intimate of God."²⁰⁶ In contrast to Bible, I hold that the CI's postulate of genuine physical acausality conflicts with the Christian doctrine of *creatio ex nihilo*, which entails that all things are dependent on God for their being and behavior. If God is rational, how could he instantiate indeterministic irrationality in the world? Further, if he did instantiate indeterminism in the world, how does he govern creation? Nicholas Saunders describes the difficulty as follows.

²⁰⁴Stanley L. Jaki, *The Road of Science and the Ways to God* (Chicago: Chicago University Press, 1978), 14-15; Nancy R. Pearcey and Charles B. Thaxton, *The Soul of Science: Christian Faith and Natural Philosophy* (Wheaton, IL: Crossway Books, 1994), 22, 29.

²⁰⁵Rodney Stark, *For the Glory of God: How Monotheism Led to Reformations, Science, Witch-Hunts, and the End of Slavery* (Princeton: Princeton University Press, 2003), 147.

²⁰⁶Bible, "Metaphysical Implications," 183-84.

It seems difficult to see in what sense indeterminism might be created and sustained by God or, to put it another way, how indeterminism and general divine action might be related. . . . Indeed the only sense in which indeterminism appears coherent is as a product of a divine kenosis, or God voluntarily withholding his knowledge, concerning its mechanism. However if this is the case then we must address the problem of how God is active in some indeterminate processes without compromising this mechanism or his lack of knowledge of it.²⁰⁷

The notion that God instantiates indeterminism in the world is problematic in light of the doctrines of creation, omnipotence, and omniscience, except in the event that one is willing to modify these classical Biblical doctrines. Fortunately, we are not forced to incorporate indeterminism into our quantum ontology. As Polkinghorne says, how we construe indeterminism is a matter of metaphysical preference.

Unpredictability is an epistemological property and there is no inevitable connection between epistemology and ontology. What connection we make is a matter of metaphysical choice and philosophical contention. In particular, questions of the nature of causality are always ultimately metaphysical in character, as the unresolved dispute between Bohm and Bohr about whether quantum theory should be considered deterministic or indeterministic makes only too clear.²⁰⁸

In light of the problems genuine indeterminism presents for the Christian doctrines cited above, I believe it is best to declare quantum indeterminism to be nothing more than a marker of current epistemological limitation, a limitation that may be resolved as science progresses.

Chapter Summary

The CI is the product of a small band of influential, privileged physicists who by and large shared a fondness for irrational views of the world. When quantum physical anomalies began to arise repeatedly in experiments throughout the first quarter of the twentieth century, Bohr and his associates were satisfied that this was evidence for genuine irrationality in nature and therefore decided against the more sensible view that said the anomalies were indications that quantum theory was incomplete and that more re-

²⁰⁷Nicholas Saunders, *Divine Action and Modern Science* (Cambridge: Cambridge University Press, 2002), 90.

²⁰⁸Polkinghorne, *Science and the Trinity*, 79.

search was necessary. Physicists and philosophers who have not shared this penchant for irrationalist themes have laid the CI aside and gone after alternatives that better fit with classical conceptions of nature and philosophy. Importantly, at least two of them, de Broglie and Bohm, have produced scientifically feasible alternatives to the CI. When the hard science in competing scientific theories is empirically equivalent, the interpreter of physical theory is permitted to select the theory that best comports with his metaphysical presuppositions. In particular, the realist, who supposes that explanatory-power is vital to any genuinely satisfactory interpretation, is justified in selecting the interpretation that most properly accounts for such factors as cause and effect. As the CI rules out the possibility of ascribing causality to quantum phenomena, the realist is within the bounds of properly conducted theory-selection to reject the CI in favor of any empirically equivalent theory that more suitably provides explanatory power.

Adherents to the Christian worldview should reject the CI on the grounds that it is a philosophically-conditioned interpretation that is sure to be overturned as additional empirically equivalent interpretations are put forward. Furthermore, the CI's basically irrational outlook on the physical world leads to all sorts of revisions of classical and Christian concepts of logic, truth, and causality. Since Bohm and de Broglie have put forth interpretations of quantum theory that are no less empirically meritorious than the standard view, and since the standard view is so problematic for Christian concepts about our God-made world, rejecting the CI is the best option for the Christian interpreter of quantum physics.

CHAPTER 6

CONCLUSION

The critical response to quantum mechanics among Christians is as yet underdeveloped, I believe. William Lane Craig has perhaps outpaced all other evangelicals in addressing issues in quantum mechanics as they arise in the scholarly debate over the *kalám* cosmological argument. His conclusion about quantum mechanics in general is that the science is “inchoate, incomplete, problematic, and poorly understood.”¹ Similarly, William Brown has suggested that quantum physics as we know it “may go the way of all flashes and end up in the physics graveyard” with other discarded theories from the annals of history.² I believe Craig and Brown are both correct. I also believe that much more work needs to be done before an adequate Christian response to the CI is achieved, and I offer this dissertation as a small part of that project.

The Copenhagen interpretation of quantum physics is objectionable from the Christian worldview standpoint because it is ill-suited or contradictory to Christian beliefs about the world and the God who made it and because, scientifically speaking, there are alternative interpretations to quantum theory that are at least as plausible as Bohr’s offering. Most likely quantum theory itself is incomplete. While the incompleteness postulate cannot be *proven*, it can feasibly be presupposed as a response to the anomalous features of current quantum theory.

While we wait for quantum theory to cross over from incompleteness to

¹William Lane Craig, “The Caused Beginning of the Universe: a Response to Quentin Smith,” *The British Journal for the Philosophy of Religion* 44 (1993): 629.

²William E. Brown, “Quantum Theology: Christianity and the New Physics” (paper presented at the annual meeting of the Evangelical Theological Society, Portland, OR, March 1988), 8.

greater comprehension of quantum reality, it seems best to adopt what Norris identified as qualified instrumentalism.³ In this context I suggest that we speak of a quantum *framework* rather than a fully developed quantum theory. This approach allows us to carry on turning out the many benefits of quantum science even as we admit that we do not fully understand how said benefits are made possible. We do not comprehend the quantum framework adequately, but we do know how to make it work to our advantage in many different industrial, medical, and technological applications. The realist can comfortably adopt this brand of instrumentalism because he takes it to be a temporary expedient that is forced upon him by the difficulty of adroitly piercing the quantum realm under current experimental capacities. This difficulty is particularly restrictive in the search for hidden variables, for these may be vanishingly small even in comparison to the bantam-like quantum entities with which we are somewhat more familiar.

Norris's suggestion that we adopt qualified instrumentalism with respect to quantum mechanics bears similarity to what J. P. Moreland has expressed in his so-called "eclectic" model for philosophy of science. An eclectic model, Moreland says, uses either a realist or antirealist approach on a case-by-case basis when integrating science and theology.⁴ Were I to adopt Moreland's language, I would suggest that we should presently be anti-realists with regard to the theoretical postulations of quantum physics. However, I prefer Norris's suggestion that we adopt a temporary instrumentalist approach, for this makes clearer the fact that we are holding out hope for a realist turn in quantum physics. In fact, we may even speak of a "convergent realism" which supposes that as a general movement science progresses steadily toward truth.⁵ Applied to quantum mechanics, the realist could feasibly say that alternative interpretations of quantum mechanics are part of

³Christopher Norris, *Quantum Theory and the Flight from Realism: Philosophical Responses to Quantum Theory* (New York: Routledge, 2000), 35.

⁴J. P. Moreland, *Christianity and the Nature of Science: A Philosophical Investigation* (Grand Rapids: Baker, 1989), 14.

⁵John Taylor, "Science, Christianity and the Post-Modern Agenda," *Science and Christian Belief* 10 (1998): 165.

the convergent realist program inasmuch as they posit classical features like causality and observer-independent existence for quantum systems even though we currently lack definitive empirical evidence for these features.

So what of the theology-science dialogue? Should Christians decline to discuss the ramifications current quantum theory has for theology and restrict themselves to discussions of less speculative science topics? Robert John Russell considers this possibility in light of the fact that the dominant interpretation, the CI, is no better empirically than Bohm's alternative and thus might have been rejected, such that the current understanding of quantum physics *could have* been drastically different had history shaken down a little differently.⁶ Russell ultimately rejects this option on the grounds that Bohm is not entirely classical either, by which I suppose he means that quantum theory would be problematic for the theological discussion even if Bohm had won out over Bohr, and that *all* scientific interpretations are underdetermined metaphysically.⁷ Hence, the theologian is taking a risk anytime he assumes the correctness of a given scientific theory he uses in his theology project. Part of what drives Russell's confident use of quantum theory is the fact that he is doing *constructive* theology, not natural or systematic theology. "Hence a change in science or in its philosophical interpretation would at most challenge the constructive proposal at hand, but not the overall viability of a theology of divine action in nature, whose warrant and sources lie elsewhere in Scripture, tradition, reason and experience."⁸

It is well that Russell believes such changes will not adversely affect his theological task, for he believes it is "virtually certain" that quantum physics as we currently

⁶Robert John Russell, "Special Providence and Genetic Mutation: A New Defense of Theistic Evolution," in *Evolutionary and Molecular Biology: Scientific Perspectives on Divine Action*, ed. Robert John Russell, William R. Stoeger, and Francisco J. Ayala (Vatican City: Vatican Observatory Publications, 1998), 218.

⁷Ibid.

⁸Ibid.

know it will eventually be replaced by a new theory.⁹ Russell summarizes the situation as follows.

The response chosen here, then, is to engage in this conversation, but in full realization of the tentativeness of the project. Clearly, we must keep in mind not only that a future theory might undercut the positions taken here but also that existing alternative interpretations of quantum physics already have the potential to do so.¹⁰

Thomas Tracy is likewise aware of the tentativeness of current quantum theory, and yet with Russell he concludes that quantum indeterminism is suitable for use in constructive theology on the condition that such a theology is interested in establishing the reality of an open-structure to the world.¹¹ Elsewhere he concludes that theological proposals based on quantum indeterminism should be presented as “tentative and provisional hypotheses” that take into account the uncertainty and difficulty of interpreting quantum physics.¹²

I believe Russell and Tracy are mistaken to proceed on the basis of current quantum theory. While all theological and apologetic endeavors will, to some extent or another, include constructive elements drawn from such areas as philosophy and experience, both theology and apologetics should proceed on a firmer basis than is provided by the CI of quantum physics. As demonstrated above, the CI is by the design of its authors closely wed to irrationalist themes in philosophy. Realists of this and future generations will work hard to overturn the CI for this reason, and the history of science encourages us to believe that they will succeed. Furthermore, the CI is no better, scientifically speaking, than several of its competitors. That several of these competing interpretations, such as that developed by de Broglie and Bohm, forswear major irrationalist elements of the CI

⁹Robert John Russell, “Does ‘The God Who Acts’ Really Act? New Approaches to Divine Action in Light of Science,” *Theology Today* 54 (1997): 57.

¹⁰Ibid.

¹¹Thomas F. Tracy, “Particular Providence and the God of the Gaps,” in *Chaos and Complexity: Scientific Perspectives on Divine Action*, ed. Robert John Russell, Nancey Murphy, and Arthur Peacocke (Vatican City: Vatican Observatory Publications, 1995), 316.

¹²Thomas F. Tracy, “Divine Action and Quantum Theory,” *Zygon* 35 (2000): 896.

and yet still account for the empirical results of quantum physics indicates that there is absolutely no compelling reason, short of philosophical predisposition, to favor the irrational themes presented by the CI over the more rational themes of alternative interpretations. Finally, the fact that the CI presents alternative views of truth, such as that portrayed in the doctrine of complementarity, indicates that this view of quantum physics represents a significant confrontation with the Christian worldview.

In rejecting the CI for use in Christian theology and apologetics, I do not intend to imply that the Christian worldview necessitates the sort of hard, inviolable, naturalistic physical determinism associated with nineteenth-century naturalism, for obviously this sort of thinking raises problems for divine action. Rather, I believe that causal factors ought to be regarded as universally operative in natural processes, and that God himself is the author of said causality. With Vern Poythress, I maintain that natural law and its causal regularities, insofar as we have properly understood them, are descriptions of what God himself does via his providential governance of the natural realm.¹³ Hebrews 1:3 indicates that Christ upholds the universe by his word of power. In Colossians 1:17, Paul teaches that all of creation holds together in Christ. In Nehemiah 9:6, the priest Ezra speaks of God as the Creator and Preserver of all creation. This leads us to expect a form of compatibilism between scientific and theological descriptions of natural events. The possibility that we may satisfactorily describe a given natural event by purely physical causal factors does not mean that the story is at an end. What occurs naturally is also a reflection of divine action. Thus, the meteorologist may describe natural causes for a rainstorm, but the Christian sensibly prays that God will replenish his earth with water. The zoologist can describe the calving of deer in naturalistic terms, and yet it is no less true that, as Psalm 29 reports, the voice of the Lord makes the deer give birth. The attempt on the part of some theologians to celebrate quantum indeterminism as an opening for divine action is mistaken because it erroneously conceives natural law as problematic

¹³Vern S. Poythress, "Why Scientists Must Believe in God: Divine Attributes of Scientific Law," *Journal of the Evangelical Theological Society* 46 (2003): 112.

for divine action. God is the Lord of natural law; he suffers no strictures from the causal factors operative in the natural realm he created and governs.

The issue of human freedom is, I think, more complex. I believe the Christian should *not* expect that natural science would be able to describe human consciousness, let alone human volition, as a function of purely physical processes. A purported proof that such operations are physically determined would indeed be problematic for the Christian worldview, for it would raise the specter of automation for human agents in a way that not even Calvinists would be able to incorporate into the compatibilistic account of the human-divine relationship. Nevertheless, genuine physical indeterminism cannot be the basis for free rational volition for the reason cited in chapter 4. The point hardly seems in need of supporting argumentation: irrational chance cannot be translated into sensible choice. If the quantum entities that compose the neural networks of my brain interact acausally, in what way may I rope their chaotic output and bring out of it the sort of order necessary to drive my sentience? This possibility has not yet been demonstrated, and I expect it cannot be done. And of course, as argued above, even if someone eventually produces a compelling account of how indeterminism can lead to rational volition, there remains the problem that the whole project rests on the CI of quantum physics, an interpretation whose days of favor are surely numbered.

Whatever direction quantum theory takes in years to come, one thing seems clear: the CI is no better than the scientific and philosophical merits on which it stands. As this present study has demonstrated ample reason for questioning these merits, it is best to conclude that the CI is not suitable for use in formulations of Christian theology and apologetics.

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ABSTRACT

THE COPENHAGEN INTERPRETATION OF QUANTUM PHYSICS: AN ASSESSMENT OF ITS FITNESS FOR USE IN CHRISTIAN THEOLOGY AND APOLOGETICS

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This dissertation examines the suitability of the Copenhagen interpretation of quantum physics for use in Christian theological and apologetic endeavors. Chapter 1 introduces basic issues in quantum physics in non-technical language and defines the basic position of the Copenhagen interpretation.

Chapter 2 gives a thorough account of the core interpretational components of the Copenhagen interpretation and indicates that some of these set up potential conflict with Biblical-based Christian beliefs about God and the world He made. The chapter also discusses how famed scientists such as Albert Einstein and Erwin Schrödinger attempted but failed to dissuade the physics and philosophy communities from adopting the Copenhagen interpretation by formulating landmark thought-experiments that aimed to expose absurdities entailed by said interpretation.

Chapter 3 examines how scholars and popular-science writers have applied the Copenhagen doctrines to sociology, philosophy, and science. Topics include feminism, race relations, finance, business management, philosophy of science, epistemology, logic, and the sciences of consciousness and cosmology.

Chapter 4 discusses applications of the Copenhagen interpretation in metaphysics and theology, with particular emphasis on applications in Eastern and holistic worldviews as well as debates about free-will and divine action in Christian theology.

Chapter 5 attempts to show that the Copenhagen interpretation is unsuitable for adoption in Christian theological and apologetic endeavors for several reasons. First, the Copenhagen interpretation was forged by a handful of philosopher-physicists who consciously sought to ensconce indeterminism as an ontological rather than merely epistemological element of quantum theory. Second, there are several scientific and science-historical counter-indicators to the Copenhagen view. Third, several entailments of the CI run counter to important elements in the Christian worldview.

Chapter 6 gives a summary assessment of the Copenhagen interpretation and suggests avenues for continuing the science-theology dialogue in light of the current state of quantum science.

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