

The Copenhagen Interpretation of Quantum Mechanics: An Introduction and Worldview Assessment

Jeremy Royal Howard

Jeremy Royal Howard holds a Ph.D. in Christian Apologetics and Worldview Studies from the Southern Baptist Theological Seminary. He has held numerous church positions, including head pastor, and currently works as an independent writer. He is co-author of *The New Eve: Smart, Bold Femininity in a World of Opportunity* (Broadman & Holman, forthcoming 2008) and co-editor of *The Men's Fraternity Bible* (Broadman & Holman, 2007).

By the science of physics we discern something of the powerful logic that stands behind the world. In tracing the ominous sweep of faraway giants in the dark of space, in following the mechanics of nutrient transport in the human circulatory system, in setting man's feet on the surface of that lesser of two great lights, the moon—in these and countless other exercises we are not eyeing cold trivia about our world; we are learning yet again something of He who stands back of it all.

Physics does not yield a full-blown theology, but by its light we see evidence of a God of order, consistency, and deeply powerful intellect. Physicists believed this once. From Newton's ascendancy to the dawn of twentieth century, most scientists held some form of Christian belief. They also assumed it would be possible to describe all physical entities by Newtonian physics. On this assumption, tracing the activities of any inanimate object should be as simple as obtaining values for position, momentum, and trajectory, and then projecting outcomes by Newton's laws. Underlying this are presuppositions that the world is rational in structure and operation and that the scientific investigator is a mere observer rather than a participant in the experimental results he obtains.

Confidence in classical mechanics was so pervasive that some believed an omni-

scient intelligence could know the future exhaustively if it could grasp perfectly in an instant all the forces, components, and relations that compose the natural realm.¹ But foretelling the future based on physics was never more than fairy tale. The fact is humans are not omniscient and everyday mechanical systems can exhibit chaotic behavior.² Thus, mechanical determinism is an ideal that is inapplicable to any system. Nevertheless, the inability of Newtonian mechanics to eliminate chaotic elements is more a result of the investigator's *limited knowledge* of relevant factors than genuine irregularity in the natural order.³ This is an important distinction from the tendency among physicists who adhere to the Copenhagen interpretation (CI) of quantum mechanics (QM) to attribute quantum chaos not to investigative incapacities but to the very nature of quantum entities. In summary, though determinism based on Newtonian mechanics is impractical, it nevertheless remains the case that, *in principle*, the Newtonian outlook sets up an expectation that future states of a mechanical system can be predicted by accounting for all present variables. Order begets order in a mechanistic universe.

Given the success of the Newtonian program, scientists operating up to the dawn of the twentieth century expected that even the microphysical world would prove to be orderly. The realization that it

is not jolted physicists out of a centuries-long habit of mind, and the result has been an “outrage” that has not abated in a century of years.⁴

Introduction to Quantum Mechanics

“Quantum” refers to the smallest units into which a thing can be divided. In QM, it refers to the tiny packets of energy by which atomic exchanges occur. Atoms do not trade energy in regular portions; rather, they absorb and emit 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 quanta of that energy. This irregularity evokes a host of questions, chief of which is: are quantum entities lawless? Experts are divided over whether or not this question has been answered.

The Problem of Light

The odd manner in which atoms manage energy is but one of the quantum anomalies which seem to belie Newtonian expectations about an orderly, rational world. Consider light. Is it made of waves or particles? Particles are site-specific. If a particle happens to be resting on the tip of your nose just now, it cannot presently be found anywhere else in the universe. A wave, on the other hand, has *spread*. It can be here, there, and all around.

Scientists wishing to determine whether photons are particulate or wave-like run into a difficulty, however, for experiments seem to indicate that photons can behave as *either particles or waves depending on what kind of measurement the scientist conducts*.⁵ Experiments also imply that photons “decide” how to behave based on the destinations of photons that precede

them and follow them through the testing apparatus. In other words, it appears that a certain “peer influence” is afoot, as if photons dialogue with one another across time and distance, take note of the experimental machinery arrayed around them, and then *decide* whether to be particles or waves. This uncanny behavior leads to an obvious problem for the experimenter. While the act of measuring macroscopic systems changes the native state only negligibly (for instance, measuring wind speed slows the wind only insignificantly), many theorists believe measuring a quantum system actually makes it what it is! It is as if the scientist is more “creator” than “explorer.” Hunt for a particle, and a particle you find. Seek a wave, and it is there in place of the particle. Search for the quantum reality that exists apart from your biasing the situation, and you will find yourself shutting down your machinery on your way out the door.

Quantum Probabilities

Physicists use “wavefunction” as a catch-all term that signifies that all we can know about a quantum system are probabilities about things like position, momentum, and energy.⁶ Thus, whereas Newtonian mechanics aimed at precise description of entity and event, QM settles for probabilistic descriptors of both. What a quantum entity happens to be and do is at best *statistically* described. For instance, if an experimenter isolates a radioactive atom, he can be confident that it is set to decay at some future time. However, he does well to go on with her daily activities, for the exact time of the impending decay event is unknown. He 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 door to the quantum domain.

Non-locality

In classical physics, cause-and-effect is a 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? Anyone suggesting that a cue ball on a *nearby* table sent D racing would rightly be dismissed from the discussion.

Not so in quantum billiards. After seventy years of trying to dispel it, genuine non-locality seems to be a settled fact of quantum reality. 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.

The Current State of Quantum Mechanics

Despite its anomalies, quantum theory (QT) is one of the most successful science theories in history, leading to many technological advancements.⁷ If it works, it must be right. Right? *Maybe not*. The fact is physicists are in the dark about the meaning of QM.

Nobody understands quantum mechanics. So do not take the lecture too seriously . . . 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.⁸

This advice, a veritable charter statement for the CI, amounts to the following: Give up trying to conceptualize QM. Live with the paradoxes, celebrate them even, but forego the search for rationality.

Formalism and Interpretation

How can QT be fruitful and yet mysterious? The answer lies in the distinction between formalism and interpretation. The formalism is "a set of equations and a set of calculational rules for making predictions," while the interpretation offers ontological explanations for the observed phenomena.⁹ One is about math; the other about meaning.

In QT, it is the *interpretation* that is mysterious. Since the formalism is all one needs to conduct experiments, most practicing physicists use the formalism and entirely ignore the controversy over interpretation. Since a key difference between the CI and alternative views is the question of whether or not quantum indeterminacy is a reflection of nature itself or just current conceptual and investigative limitations, the tendency for physicists to practice QM 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 formalism or the empirical results obtained in the laboratory. Rather, the decision is decided on one's personal philosophical convictions.¹⁰ Thus, it is no surprise that most physicists regard the interpretation of QT as baggage that is best left curbside, for scientific fact is far more relevant than philosophical opinion when one is in the hunt for a research grant. Nevertheless, when pressed to choose an interpretation,

physicists typically cite the CI. In so doing they are only repeating the line that was fed to them in college. 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 interpretive issues, and hence never bothered to question what they had dutifully accepted by rite of 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 (CI)

The CI takes its name from Niels Bohr's hometown where he and physicists such as Werner Heisenberg and Wolfgang Pauli collaborated to provide an *interpretation* for QT. A sample of core components of the CI includes the following: (1) the QT, as developed by 1930, is as complete a description of QM 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 quantum reality, such that wave and particle characteristics are said to be "complementary," which on Bohr's terms means quantum nature is paradoxical, and (5) that quantum systems remain

indeterminate (no real values) until they are measured.¹¹

The goal of this article is to show that the CI is not suitable for use in Christian theological formulation or apologetic engagement. There are two main reasons this is so.

First, the CI is not the assured deliverance of science. The CI is in fact more a product of a post-WWI German philosophical bent that overthrew mechanistic conceptions in favor of irrationalist viewpoints. As these tastes have been sustained for nearly a century now, popularized and ensconced by postmodernism, the CI has continued to dominate QT in part because of its fitness with regnant worldview themes. In this light, the CI is vulnerable to the essential inevitability of a future worldview exchange. When irrationalist inclinations pass from the scene, the CI 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. Furthermore, the CI is not the assured deliverance of science because at least one alternative theory rings in as empirically equivalent to Copenhagen while retaining somewhat more classical assumptions about rationality and causality.¹²

Second, aspects of the CI are in conflict with Christian belief. In particular, belief that the world is rationally structured and is reflective of God's own rationality is swept away by Copenhagen irrationality. A longstanding tradition in 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* vouchsafes that our minds are capable of receiving true information about the world God made.¹³ Furthermore, CI's principle of complementarity opens the possibility of accepting contradictories as varying parts of a holistic system. This supports 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.

A Deeper Look at the CI *Indeterminism*

The CI maintains that indeterminism is a reflection of genuine acausality on the microphysical level. Hence, there is no hidden (currently unknown) causal system embedded in QM that awaits discovery.¹⁴ Quantum non-locality is offered as one of the proofs for this 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 hope of identifying causal factors is lost. Another argument for acausality stems from the surprising role the scientist plays in quantum measurements. If a scientist cannot describe the autonomous operations of a quantum system because her very measurements have produced the effect measured, causality has passed beyond our purview.¹⁵ Thus, repudiation

of causality is said to be the non-negotiable first step if progress is to be had in QM.¹⁶

Complementarity

By "complementarity" Bohr means "contradictariness," a reversal of the term's typical usage.¹⁷ Bohr was not consistent in explaining all the entailments of complementarity, but Heisenberg explains that complementarity means the scientist must hold simultaneously two contradictory concepts for quantum entities: wave and particle.¹⁸ Bohr took this as a justification for recasting rationality in terms that allow one to accept contradictory options simultaneously without committing logical fallacy.¹⁹ Thus, while waves and particles are contradictory things, Bohr accepts both as proper and final descriptors of quantum reality. This view is unacceptable on any realist construal of science because it prohibits an intelligible conception of quantum nature.²⁰

True to his physics, Bohr placed the Yin-Yang symbol on his coat of arms for the Danish Order of the Elephant and stenciled "Opposites are Complements" above it. For Bohr, QM justified Eastern concepts of reality. And not surprisingly, he applied complementarity to issues outside physics. For instance, he believed that "whenever you come with a definite statement about anything you are betraying complementarity."²¹ Furthermore, he expected that "the quantum revolution would ultimately lead to a general complementaristic philosophy of empirical knowledge."²² That is quite an ambitious statement, especially since it would overturn many fundamental beliefs about the world. In particular, complementarity undermines a key presupposition of science: that nature can be understood,

explained, and modeled rationally.

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].²³

The Measurement Problem

As defined by the CI, the measurement problem means acts of measurement do not provide physicists with information about the preexistent status of quantum systems; rather, acts of measurement force fundamentally indeterminate quantum systems to "develop" certain qualities. While it is debatable whether or not Bohr took this to mean that quantum systems do not exist prior to being observed, significant interpreters in his tradition insist that he meant exactly that. Roger Penrose, for instance, says that on Bohr's view there is no 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.'"²⁴

According to David Lindley, the only way to avoid these implications is to refute the CI and deny that indeterminacy is a real feature of QM.²⁵ Einstein and Erwin Schrödinger set out to do this very thing by proposing thought-experiments that aimed to show the absurdity of the CI.²⁶

Erwin Schrödinger's Cat

In 1935, Erwin Schrödinger set out to win the physics world back to Newtonian sanity by discussing a hypothetical scenario involving atomic radiation and a housecat. He aimed to confront the Copenhagen contention that a quantum system is in superposition (has no definitive values) until it is measured.

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 [Geiger counter] to monitor it. The detector is wired up to release a cloud of poison gas into the chamber if the radioactive material decays, and living in the chamber 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.²⁷

Naturally, no one has performed this experiment. Seemingly it is enough just to mull the hypothetical scenario and grasp its absurdity. Schrödinger was sure this would spell the end of Copenhagen excesses, but amazingly the cat paradox is regularly celebrated as a "strange-but-true" signal of just how odd the quantum world really is.

The EPR Experiment

While the physics crowd went after quantum oddities, Einstein stubbornly beat the old-world drum trying to call

everyone back to local causality. In so doing he digressed from quantum progenitor to QT's "deadbeat dad."²⁸ Einstein's fall-out with QT began when he shifted from positivism to thoroughgoing realism, emphasizing causality and observer-independence. In 1935 he took the battle to the heart of the CI by producing a thought-experiment known as EPR. EPR maintains that "every element of the physical reality must have a counterpart in the physical theory."²⁹ Hence, a theory is *incomplete* if some aspect of the reality it seeks to describe is left unmentioned. Furthermore, EPR assumes that the ability to formulate predictions of a quantum system indicates that some underlying physical reality exists and determines outcomes. An adequate theory will account for that reality. The CI does not. EPR sets up a hypothetical situation in which two quantum particles come into contact with one another in a vacuum tube, form a quantum system, and are then disjoined and shuttled off in opposite directions. Once they are separated by a distance too great to allow the particles to spontaneously communicate, the particles are measured for variables such as spin or momentum. The upshot is that Einstein hoped to show that the particles will display values that indicate they had "real values" before they were measured and that these values reflect values they had when they previously formed a quantum system—such that the law of conservation holds for QM. This would counter the CI's contentions that quantum particles have no real values until they are measured and that the act of measuring one particle spontaneously forces its faraway counterpart to change its values so as to maintain anti-correlation with the measured particle.

For Einstein, non-local causality was "spooky action-at-a-distance," a plot apropos for ghost stories, not physics. EPR's argument that QT itself is incomplete hinges on the impossibility of such anomalous action. The only other option is to accept the absurdities of non-locality and observer-created reality as true facts of the universe. Predictably, the Copenhagen theorists embraced these absurdities, thus neutralizing the albatross Einstein had crafted for them. Commentators typically agree that EPR failed to accomplish its purpose.³⁰ Nevertheless, Bohr's rebuttal of EPR is unsubstantial and boils down to an appeal from positivism.³¹ That his response was so highly touted indicates something of the popularity to which the positivist framework had risen by the 1930s.

Putting EPR to the Test

Most physicists sided with Bohr against EPR, but so long as EPR was merely hypothetical the matter could not be settled by laboratory trial. John Bell elucidated the first steps toward rectifying this shortfall by developing an experiment that made it practical to test Copenhagen's non-locality claim.³² Bell held out hope of vindicating EPR, but when the tests were conducted the CI's insistence on genuine non-locality in QM was by all appearances justified. In 1981-82 a team of physicists found strong evidence for quantum non-locality.³³ By 1997, tests showed that entangled particles separated by eleven kilometers retain their causal linkage, as if they were immediately present to one another. This is like bruising your brother's arm while you sit on a sofa across town from where he sits.

Might locality be recovered in future experiments? Most theorists doubt it.

While one cannot help but feel the weight of current evidence, I suggest it is reasonable to hope that non-locality will someday be revised or supplemented in such a way as to lessen the present difficulty. As Wesley Salmon has said, “I do have a profound sense that *something* that has not been explained needs to be explained.”³⁴ The history of science supports this reticence. Scientists have long taken the appearance of distant action to be a sign that some variety of local causal agency exists but is *presently unknown*.

Classical Language and Completeness

Another key aspect of the CI is the insistence that though classical concepts are inapplicable in microphysics, classical language must be retained when describing quantum phenomena.³⁵ This serves to heighten the sense of paradox in quantum theory, as when Copenhagen theorists retain terms like “particle” and “wave” to describe quantum systems that fit neither bill in any cognizable sense. This practice runs counter to the realist desire to rule out paradox by incorporating new terms/concepts for discoveries that cannot properly be encompassed by traditional terminology. For instance, some theorists favor ditching the Copenhagen paradox regarding wave-particle duality by 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.³⁶ The realist insists that it is our inchoate understanding rather than nature itself that gives rise to paradox in QT.

The chief result of the claim that QT is complete is that the search for “hidden variables” is useless. Hidden variables

are variables that are “hidden” from us because we *currently* have no empirical proof for their existence. On the realist view, there must surely be hidden variables operative in QM—factors that, if we knew them, could explain away the appearance of such things as acausality and non-locality. In essence, then, he who appeals to hidden variables to escape such paradoxes is making that claim that QT is *incomplete*. This is the contention of all alternatives to the CI.

Irrationality

Finally, the Copenhagen emphases on indeterminacy, acausality, and observer-created reality forge an irrational concept of nature. K. V. Laurikainen backs this claim and indicates how the CI 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*.³⁷

In other words, if the Christian West could just get over its fixation on thinking the world is rational the CI would *not* be difficult to embrace.

Worldview Applications of the CI

Since 1927 the CI has been the only sanctioned interpretation of QM. It is the view of the textbooks, the position espoused in the lecture halls, and the interpretation parsed in the journals. To the extent that the CI is thought to describe truth about the physical universe it is fitting that attentive persons would make applications in fields outside physics.

Philosophy of Science

The conflict between the CI and alternative interpretations is a component of the larger debate 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.³⁸ Bohr himself might have been pleased with this outcome, for it is certainly possible to read him as an anti-realist.³⁹ In fact, anti-realism has been the predominant position of Copenhagen theorists from the beginning.⁴⁰

The anti-realism circulating among quantum physicists has spread to philosophers such as Hilary Putnam, who gave up robust realism in response to QT.⁴¹ Norris concludes that the CI puts a Kantian spin on anti-realism because it reverses the realist priority between ontology and epistemology by taking epistemological problems in QT to be a reflection of a sort of "noumenal" ontology.⁴² Arkady Plotnitski agrees, accepts the CI, and concludes that it implies the end of all realism, "mathematical, physical, or other."⁴³

The CI also fits well with positivism. 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. It is not hard to guess what impact this has on metaphysics. Richard Kitchener says the CI reduces to the assertion that there is no reality behind quantum phenomena.⁴⁴ 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, phenomen-

ists, instrumentalists, contextualists, and so on."⁴⁵ Hence, the CI ultimately leads to metaphysical pluralism. "Since quantum physics makes no assertions about what is *ultimately real*, it cannot be in conflict with one's metaphysics."⁴⁶ Kitchener's argument depends on Kantian elements in the CI. The "real" is shoved into a noumenal caste and so in this sense room is made for "faith" in whatever metaphysical system you choose. Metaphysical pluralism is possible because metaphysical certainty is *impossible*.

Truth and Reason

Danah Zohar says the complementarity doctrine signals the invalidity of either/or thinking. "We have to learn to get beyond apparent contradictions."⁴⁷ She also highlights analogies between QM and the search for religious truth and concludes that all truths are only "partial expressions of a 'higher' or a 'deeper,' and ultimately inexpressible, truth."⁴⁸ 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."⁴⁹

It is tempting to suppose that Zohar is extending the CI beyond the intentions of its founders, but this may be mistaken. Max Born says, "ideas such as absolute certainty, absolute precision, final truth, etc. are phantoms which should be excluded from science."⁵⁰ That he believes the loss of absolute truth should extend beyond the claims of strict science is made obvious by the following elaboration. "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."⁵¹

Born holds that QM has gifted the world with a mandate for greater epistemic humility, but relativism is the actual result if "the belief that there is only one truth" on a given matter is ruled out completely.

Cosmology

Science has compiled impressive evidence for a finite universe. Cosmologists were initially reluctant to concede this because much scientific and philosophic capital had been invested in models that would not admit that the universe had a beginning or Beginner. Today, the proof that the universe must be explained by some version of the Big Bang model is "impressive almost to the point of hubris."⁵² In this light, one might expect that theistic conclusions regarding ultimate origins are inevitable, but in fact a case for an atheistic universe supposedly remains an option for adherents to the CI. QM comes into play in models for the universe's origin because early in the universe's expansion quantum particles were crowded together closely enough that quantum effects were significant. Elements of the CI are said to bear on this in several ways, but we shall discuss only two of them.

John Wheeler says quantum phenomena are not true phenomena until they are observed.⁵³ The importance of the "act of detection" is even

more important in light of Wheeler's delayed-choice experiments, which many physicists believe demonstrate that acts of measurement decide the near-past reality of quantum entities.⁵⁴ Extending his theory into cosmological origins, Wheeler says that though his delayed-choice experiments involve only a fraction of a microsecond's delay, in principle the delay may as well have been billions of years. From this Wheeler moves to a radical conclusion: we create the past by measuring it. "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."⁵⁵

Wheeler brings this speculation to a crescendo when he asks if "Big Bang" might be a shorthand way of describing what billions of "elementary acts of observer-participancy" have brought about as they reach into the past.⁵⁶ The implication is that we created the universe by observing it. It is only by virtue of the popularity of the CI that he can present this as a piece of science rather than particularly imaginative science *fiction*.

Taking a tack that relies more on the supposed acausality of QM, P. W. Atkins 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 and taking their existence from the pattern they formed, defined a time."⁵⁷

Quentin Smith echoes this by claiming that QM shows that "many particles" simply pop into existence without a cause.⁵⁸ Smith even argues that in light of QM, "it is highly probable that a Universe with our characteristics will come

into existence without a cause.”⁵⁹ Smith’s case hinges on the appeal to acausality as supplied by the CI. He thinks one result is the ability to get particles for free—the naturalistic origin of material micro-reality. There are several difficulties with Smith’s proposal. The chief of them is this: the virtual particles he claims arise due to violations of conservation are not created *ex nihilo*, but in fact represent a transition from *existing* energy to matter.⁶⁰

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’!⁶¹

Hence, the claim nature produces quantum particles out of thin air involves a bit of scientific smoke-and-mirror.

Holism and Panpsychism

All material objects are made of quantum particles. This leads some to claim that QM applies to *everything* and that quantum entanglement (where quantum particles affect one another even if widely separated) applies to the entire universe. This engenders holistic conceptions of nature and in fact Bohr himself thought the CI implied holism. Indeed, holism and process philosophies are the only metaphysics that are compatible with the new physics.⁶² Pauli would agree, for he treated matter and psyche as a holism.⁶³ This holism is connected with his “emphasis on the *irrationality* of reality and the essential *role of the unconscious* when forming a picture of the world.”⁶⁴ Menas Kafatos and Robert Nadeau believe quantum holism implies that “human consciousness participates in the life of

the cosmos” in causative ways.⁶⁵ On this basis they reject the Judeo-Christian belief 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.”⁶⁶ It seems that a basic panpsychism is shaping up here: the view that mind and matter are distinct elements of reality that *cannot exist apart from one another*, an implication of which is that all events are both material and mental.⁶⁷

There is at least one definitive scientific reason to deny that quantum entanglement justifies holistic or panpsychical entailments. While experiments carried out in highly controlled conditions 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 is that entanglement between any two particles is fleeting and soon becomes non-existent.⁶⁸

Eastern Parallels

Fritjof Capra claims QM *forces* us to see the world from an Eastern perspective.⁶⁹ Gary Zukav says the CI has initiated a “monumental reunion” between rational and irrational aspects of our psyches.⁷⁰ While Capra and Zukav are unreasonably bold, in reality they are building on a line of implication laid down by Bohr himself, who said atomic theory parallels the epistemologies of Buddha and Lao Tzu.⁷¹ Those parallels include emphasis on irrationality as a genuine characteristic of reality. The CI makes us uneasy because we Westerners suppress irrationality, says Laurikainen, but Eastern thought helps us accept the irrational world opened to us by

QM.⁷² Interestingly, he says the tendency for Christian theologians to be closed to such things has encouraged many people to convert to Eastern views.⁷³

While there are obvious similarities between Eastern thought and the CI, popular accounts exaggerate the extent to which developments in QM verify the Eastern outlook: key differences are ignored, mere analogy is falsely presented as justifying grounds, and an Eastern apologetic agenda drives the arguments beyond their justified reach.⁷⁴

Quantum Physics and Theology

Insomuch as QT undermines the materialistic, mechanistic excess some ascribe to Newtonian physics it provides an opening for theology. No longer can the naturalist cite unfringeable mechanical laws as proof that God cannot be involved in the world.⁷⁵ Following are some of the ways QT has been employed on behalf of theology.

Free Will

Several commentators who wrote just as the CI was coming off the presses announced that QM had saved human freedom. A. S. Eddington, for instance, wrote in 1928 that the future is a fusion of causal influences and unpredictable elements.⁷⁶ Later, G. E. M. Anscombe argued that quantum indeterminism is a necessary component of reality if humans are free.⁷⁷ Arthur Peacocke shares this conviction and believes QM indicates that God has bestowed “a certain autonomy” on humans and nature itself.⁷⁸ For Peacocke, this means God’s action in the world has an “exploratory character” because the quantum indeterminacies purchase an open-endedness not even God can control.⁷⁹ Greg Boyd agrees and cites QM as

evidence for open theism.⁸⁰

There are several problems with purchasing human freedom from quantum indeterminism. First, the argument hinges on the CI as if it were the only interpretive option. It is not. Second, the argument depends on the feasibility of the link between quantum randomness and freedom of the will, but freedom and randomness are entirely different things.⁸¹ What we want to understand is how we can act “deliberately and rationally,” not “unpredictably and in a chancelike fashion.”⁸² As the Christian doctrine of human freedom insists that we are capable of making *rational* moral choices it seems clear that the Christian gains no ground by appealing to the CI.

Special Divine Agency (SDA)

Does quantum indeterminacy open a crevasse in the anti-supernaturalistic edifice of natural science? Many theologians believe so, including physicist and Episcopal priest William Pollard. Pollard believes, as per the CI, that quantum indeterminacy is a reality and not merely a result of current ignorance.⁸³ He suggests that “the appearance of chance and accident in history” is the key to SDA.

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.⁸⁴

But how can indeterminate microscopic reality affect the lawlike macroscopic world? This is the “amplification problem.” Quarks *may* be lawless, but sticks and stones are not. In that case, how can tampering with indeterminate entities

bring about real-world affects in everyday law-abiding objects? The best Pollard can suggest is that gene mutation, which can be influenced by QM, can produce macroscopic effects. So God rules via the vagaries of genetics.

Philip Clayton says the task of the theologian is not to *prove* SDA but rather to show that it is *possible* in light of current science. He thinks the possibilities are promising, for the widely accepted CI “argues for an actual *ontological indeterminacy*” which allows theologians to posit quantum-based SDA without making theology vulnerable to future shifts in science.⁸⁵ 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.⁸⁶ It is hard to escape the impression that Clayton is *hoping* rather than *arguing* here.

Arguments for SDA predicated on quantum indeterminacy are problematic for several reasons. First, there is the aforementioned amplification problem. Even if God does determine the outcomes of indeterminate quantum events, He would be unable to bring about significant *macroscopic* effects by this fact.⁸⁷ This is no slight to God, for it is just impossible that rearranging the furniture of an indeterminate realm would affect the goings on in a *consistently lawful* realm. The atoms in my coffee mug may be zinging around in a quantum craze, but the mug itself is utterly indifferent to this. Quantum indeterminacy, if a reality, has no bearing on everyday objects.

Second, Peter Hodgson says quantum SDA is problematic because of the CI’s “positivistic obscurity.”⁸⁸ Third, the attempt to explain SDA via quantum inde-

terminacy is the mark of an impoverished theology. God is Lord of creation, and as such it is unwarranted to suppose He must work within the confines of natural indeterminacies to pull off his desired ends.⁸⁹ The mere fact of 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. Thus, the law of causality does not stand outside God as a force with which he must reckon. Rather, it 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.

Philosophical Background of the CI

Scientists are not strictly objective. A researcher’s worldview significantly shapes his expectations, judgments, and hypotheses. To judge the merit of a scientific theory, it is important to know the philosophical predispositions of the theorists and judge how these have influenced their conclusions. This is especially important for the CI and the like-minded men who founded it.

Niels Bohr

As the CI spread outward from Copenhagen, Bohr’s worldview went with it. Many people regarded him “not only as teacher of physics but also as guide to life.”⁹⁰ Strangely, Bohr may have been pleased with this, for he believed his doctrine of complementarity could be a guide to life, possibly even better than religion.⁹¹

When young, Bohr aspired to write a treatise on epistemology, but the glory of

physics lured him away for a while. Ironically, QM brought him full circle. By entering physics instead of philosophy, he was able to return to philosophy with powerful new conceptual tools.⁹² Thus, Bohr's work in QT was an amalgam of philosophy and physics. What kind of philosophy? Arkady Plotnitski says Bohr's doctrine of complementarity reflects his fondness for Kant, Hegel, Kierkegaard, William James, Harald Høffding, Nietzsche, and Freud.⁹³ Høffding is particularly important because Bohr knew him personally as a boy. Høffding emphasized the psychological fragmentation of society and blamed industrialization and mechanistic conceptions of nature.⁹⁴ He also espoused "objective antirealism," which includes *denial* of the correspondence theory of truth and transcendent truth conditions.⁹⁵ Jan Faye believes Bohr's philosophy and development of the complementarity doctrine are reflections of Høffding's anti-realism.⁹⁶

Bohr's philosophy of QM relies heavily on Kant as well.⁹⁷ Indeed, Kant's phenomenal-noumenal distinction composes the whole warp and woof of the CI. Clifford Hooker says Bohr falls into the temptation Kant's successors always face: the temptation to deny the reality of the "thing-in-itself" because of the epistemological inaccessibility of the noumenal.⁹⁸

In the main, Bohr's is an anti-realist/instrumentalist approach to science. This is illustrated well by a statement he uttered about quantum reality. "There is no quantum world. There is only an abstract quantum mechanical description."⁹⁹ Inheritor's of Bohr's tradition take this to mean that physical reality cannot be ascribed to quantum entities that are not under observation.¹⁰⁰ In summary, Bohr's lifelong preoccupation with phi-

losophy colored his involvement in QM and predisposed him to "detect" irrationality in QM.

Wolfgang Pauli

Pauli and Heisenberg were also philosophically predisposed to find irrationality in QM. This is especially so with Pauli, who favored irrationality as a defense against materialism and sought to develop a framework that would unite psychology and physics.¹⁰¹ Pauli believed QT was ideally suited to this task because quantum indeterminism indicates that irrationality is a genuine feature of nature. For this reason Pauli opposed the hunt for hidden variables, fearing the search would encourage physicists to hold out against the irrationality he believed they should embrace.¹⁰²

Pauli espoused a "dark, pessimistic, irrational, and holistic realism"¹⁰³ and named Christianity as the chief obstacle to the "darkness" of irrationality.¹⁰⁴ Pauli's dislike for Christianity stemmed primarily from his rejection of the Christian belief that evil has no ontological existence but is merely a privation of good.¹⁰⁵ The Christian position, Pauli held, refuses to deal with the irrationality revealed by QM.

David Bohm's Alternative Interpretation of QM

David Bohm's alternative to the CI is complex and presents its own set of confrontations with the Christian worldview.¹⁰⁶ Nevertheless, it is more in line with realism and classical physics. Furthermore, it is empirically equivalent to the CI, which means both interpretations are on *equal footing* scientifically. This means there is "pervasive underdetermination" between these competing

interpretations.¹⁰⁷ When interpreters are faced with empirical equivalence between two or more theories, they must judge the theories based on their philosophical and epistemological virtues.¹⁰⁸ Thus, one's metaphysical preferences will decide which interpretive option is most suitable. In that case, the realist is justified if he chooses Bohm or some future alternative that is empirically equivalent to the CI. The CI is not the only game in town. Furthermore, the empirical equivalence between Bohm and the CI indicates that QT itself *is* incomplete.

The physics community rejected Bohm's interpretation for several reasons, but one of the most significant was that the CI was already firmly established, forming a society of interpretive fidelity Bohm could not infiltrate. This indicates something of the powerful role non-science forces can play in the popularization of scientific theory.¹⁰⁹

The Forman Hypothesis

Paul Forman suggests that the post-Great War social climate in which Bohr and his associates operated inclined them to emphasize irrationality in QT. Specifically, the pre-war German emphasis on science and mechanism, which established scientists as heroes and cultural leaders, was exchanged for a keenness for irrationality, acausality, and antagonism toward the hard sciences.¹¹⁰ If physicists were to recover something of their former privilege, they needed to become attuned to the new *Lebensphilosophie*. Casting aside the albatross of causality was a first step toward that end.

Forman acknowledges that his sociological model cannot be the whole truth, but believes Bohr *et al.* crafted QT to suit the obligations given them by their cul-

tural milieu.¹¹¹ This claim has provoked thoughtful response and even qualified acceptance from scientific realists.¹¹² James Gardner Murphy conducted an interview with Einstein in 1932 that indicates that a moderately strong version of the Forman hypothesis is justifiable. When Einstein stresses that scientists must salvage causality in physics, Murphy's reply encapsulates 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 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.¹¹³

Scientists do indeed live in the world just like other people, and the *Zeitgeist* ("spirit of the age") cannot fail to influence their theoretical posits. The Weimar culture's fascination with irrationalism likely played a role in the development of similar themes in QT. This conclusion is strengthened by the fact that Bohr favored irrationalist elements in philosophy *before* he developed the CI. Also supporting Forman's hypothesis is the fact of the empirical equivalence between the CI and Bohm's view. This indicates that non-science factors led to the dominance of the CI. If those factors had been different, most likely the CI would not dominate QM.¹¹⁴

Scientific Critique of the CI Demarcation

The demarcation problem asks: how do we divide the world into "speakable" macro-systems and unspeakable quantum

systems?¹¹⁵ According to the CI quantum systems are non-classical, acausal, and non-existent apart from observation. So how do we demarcate them from macroscopic systems that are classical, causal, and existent apart from observation? How many atoms must cohere before a quantum system “converts” to a classical system? Indeed, if quantum systems are acausal and non-classical, how can the addition of more quantum entities convert them to classically described macro-systems?

Correspondence Principle

The Correspondence Principle requires that a new theory (such as QM) be accepted only if it accounts for the success of the preceding theory (such as Newtonian physics) by devolving into that theory under the sort of conditions by which the preceding theory has been well confirmed.¹¹⁶ Basically, the new theory retains lower elements of the theory it succeeds and by virtue of this fact preserves explanatory power. That the CI *fails* to preserve impressively confirmed elements of classical physics indicates that a new QT is needed.¹¹⁷

The Completeness Claim

The CI claims that QT is complete, such that no paradox-erasing supplementation is possible. Astute observers have called this an “outrageous” science stopper that sets “dogmatic limitations” on theorizing and investigation, all on the basis of “obscure philosophical preconceptions.”¹¹⁸ In fact, 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 sci-

ence 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.¹¹⁹

Hidden Variables

Einstein spoke for all realists when he said that the statistical character of QT indicates its incompleteness as a description of QM.¹²⁰ In other words, there are hidden variables QT has not accounted for. This is nothing new. Scientific thinkers have postulated hidden variables since at least the fourth century BC.¹²¹ Historically, the most significant motivation for positing hidden variables is the belief that action-at-a-distance is impossible. Aristotle, for instance, said all action (or causality) is either self-motion or contact action.¹²² Either a thing has a will to move itself or else something must act on it to cause its motion. This has repeatedly been borne out in science, even when initial evidence suggested distant action or randomness was real. Take Brownian motion, for instance. Einstein successfully described the jiggling of dust motes as the effect of unseen molecules that actually follow classical causal laws. What was once thought to be genuinely random was subsequently described causally once hidden variables were discerned. In light of this and other examples where anomalies were banished by further investigation, it seems clear that the CI is falsely inflating present investigative limitations into insurmountable barriers.¹²³

Non-Locality

Proponents of the CI emphasize non-locality as a key indicator of the metaphysical implications of QM, but significant

interpreters of non-locality reject this conclusion.¹²⁴ Tim Maudlin argues that quantum entanglement can be explained via superluminal causal connections that do not involve matter or energy transport.¹²⁵ Maudlin's tactic rests on the questionable feasibility of suggesting that non-local hidden variables exist, such that some variety of non-local causal influence saves the principle of causality. This would exorcise both quantum entanglement and quantum indeterminism from QT, but it may violate Einstein's relativity theories, which insist that communications cannot be conveyed faster than the speed of light.¹²⁶ However, while energy and matter cannot convey faster-than-light influences, perhaps there is some unknown medium by which such signals can be conveyed. One thinks of the discredited ether theories in this context. Can these be resurrected? At present, the suggestions put forth by Maudlin and others are just 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 in QM.

In Defense of Realism

Realism includes the beliefs that the world exists independent of our minds and that causal factors are operative in physical systems whether or not we detect them. If scientists discover elements of reality that cannot be readily understood, the realist regards it as "unnecessary

arrogance" to suppose that the limitations and uncertainties we experience inhere the real world itself.¹²⁷ However, thoroughgoing realism with regard to QM is impossible given current limitations. The best stance seems to be realism with respect to science generally, but qualified instrumentalism with respect to QM specifically.

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.¹²⁸

In this approach, the fruitfulness of QT is preserved by the *pro tempore* instrumentalist approach while the rationality of nature is preserved by the insistence that realism is a genuine future possibility for QM.

Christian Worldview Critique of the CI

The CI makes or is the basis for worldview claims that are contrary to elements of the Christian faith. To begin with, the CI instantiates an insuperable truth problem. Zohar, Born, and others speak of how belief in transcendent, ultimate truth is harmful, and how the doctrine of complementarity provides a means of equalizing contradictory truth claims. Kafatos and Nadeau express a similar view. They believe this negates ontological dualism, transcendent truth claims, and the Christian worldview.¹²⁹ I agree. The denial that truth can be ultimate and transcendent is contrary to the biblical claim that God *is* transcendent, *is* truth, and has *revealed* truth to us. 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.¹³⁰ 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. Hence, Bohr's complementarity doctrine, which states that the opposite of a profound truth is another profound truth, simply does not comport with a Christian construal of the world, nor does the assertion that belief in exclusivist monotheistic religion is a root of moral evil.

The majority of Christian thinkers have been realists with respect to the external world and the philosophy of science. This is chiefly because the biblical doctrine of creation entails that the human mind is created in such a way as to match the intelligibility of nature.¹³¹ The "sameness" between mind and nature is secured by the fact that both are made by God to reflect His rationality. The human mind in particular is readymade for reception of truth. "Human knowledge can be regarded as a reflection of the truth originating in the mind of God. . . . 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."¹³²

The realism position is bound up with the correspondence view of truth, which is also a component of the Christian worldview.¹³³ The CI denies the very pos-

sibility 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 by humans. As we have seen, some proponents of the CI go so far as to say that our observations create past truth or even the universe itself. This undermines the Christian belief that God made the world and that our knowledge is true knowledge only insofar as it corresponds with reality 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.¹³⁴ 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.¹³⁵ Furthermore, the fact that creation was thought to be the product of a rational Designer encouraged empirical investigation of the natural realm. Del 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.¹³⁶

Vern Poythress describes natural law as the imperfect human description of the very regularities of God's own

providential care for his creation.¹³⁷ From this it follows 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 does not mean that such actions are fundamentally *irrational*. In QM, 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 and 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.

The CI's postulate of genuine physical acausality conflicts with the Christian doctrine of *creatio ex nihilo* (creation from nothing), 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:

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.¹³⁸

The notion that God instantiates indeterminism in the world is problematic in light of the doctrines of creation, omnipotence, and omniscience. 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.¹³⁹

In light of the problems genuine indeterminism presents for the doctrines cited above, it is best to regard quantum indeterminism to be nothing more than a marker of current scientific limitation, a limitation that may be resolved as science progresses.

Conclusion

Whatever direction QT takes in the future, one thing seems clear: the CI is no better than the scientific and philosophical merits on which it stands. As we have ample reason to question these merits, it is best to conclude that the CI is not suitable for use in formulations of Christian theology and apologetics.

ENDNOTES

¹This is often referred to as “Laplacian Determinism” after Pierre Laplace’s famous claim that an omniscient intelligence could predict the future if he but knew all present physical facts. Though

Laplace himself does not so name it, the vast intelligence to which he refers is commonly called “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” (Pierre Simone Laplace, *A Philosophical Essay on Probabilities* [trans. Frederick Truscott and Frederick Emory; New York: Dover Publications, 1951], 4).

²James T. Cushing, *Quantum Mechanics: Historical Contingency and the Copenhagen Hegemony* (Chicago: University of Chicago Press, 1994), 209-12.

³As 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.

⁴My use of “outrage” stems from Danah Zohar, who champions common quantum anomalies in an effort to formulate a quantum worldview. On quantum outrage, see Danah Zohar and Ian Marshall, *The Quantum Society: Mind, Physics, and a New Social Vision* (New York: Quill, 1994), 38.

⁵For a more detailed description of this experiment, see Jeremy Royal Howard, “The Copenhagen Interpretation of Quantum Physics: An Assessment of its Fitness for Use in Christian Theology and Apologetics” (Ph.D. diss., The Southern Baptist Theological Seminary, 2005), 4-7.

⁶Sam Treiman, *The Odd Quantum* (Princeton: Princeton University Press, 1999), 25.

⁷Wesley C. Salmon, *Four Decades of Scientific Explanation* (Minneapolis: University of Minnesota Press, 1989), 173; Christopher 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 Unspeakable 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.

⁸Richard Feynman, *The Character of Physical Law* (Cambridge, MA: M.I.T. Press, 1965), 129.

⁹Cushing, *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 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.

¹⁰Trevor 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.

¹¹This 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; Alan Grometstein, *The Roots of Things: Topics in Quantum Mechanics* (Boston: Kluwer Academic, 1999), 410; and Cushing, *Quantum Mechanics*, 32.
- ¹²This is a reference to David Bohm's work, which is discussed briefly below.
- ¹³Ronald 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.
- ¹⁴Plotnitsky, *Complementarity*, 72.
- ¹⁵Niels Bohr, "Causality and Complementarity," *Philosophy of Science* 4 (1937): 293.
- ¹⁶*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 Copenhagen party regularly speak of quantum acausality.
- ¹⁷John 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.
- ¹⁸Werner 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.
- ¹⁹Norris, *Quantum Theory*, 247.
- ²⁰Dugald Murdoch, *Niels Bohr's Philosophy of Physics* (Cambridge: Cambridge University Press, 1987), 232.
- ²¹Abraham Pais, *Niels Bohr's Times, In Physics, Philosophy, and Polity* (Oxford: Clarendon Press, 1991), 446.
- ²²Henry J. Folse, *The Philosophy of Niels Bohr: The Framework of Complementarity* (Amsterdam: North-Holland Physics Publishing, 1985), 170.
- ²³Shimon Malin, *Nature Loves to Hide: Quantum Physics and Reality, a Western Perspective* (Oxford: Oxford University Press, 2001), 37. Thales of Miletus, Mali notes, is often considered the first scientist because he postulated a first principle in nature and sought to order nature in accordance with it.
- ²⁴Roger 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.
- ²⁵Lindley, *Weirdness*, 111.
- ²⁶So-called "thought-experiments" or *gedanken*-experiments are hypothetical experiments scientists run through in their minds because factors such as insufficiencies in technology, funding, or access prevents them from carrying out the experiment in the laboratory.
- ²⁷John Gribbin, *Q is for Quantum: An Encyclopedia of Particle Physics* (New York: Free Press, 1998), s.v. "Schrödinger's cat."
- ²⁸George 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 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.
- ²⁹A. Einstein, B. Podolsky and N. Rosen, "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?" *Physical Review* 47 (1935): 777.
- ³⁰P. 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.
- ³¹"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." Mara Beller, *Quantum Dialogue: The*

- Making of a Revolution* (Chicago: University of Chicago Press, 1999), 153. On Bohr's response having a positivistic grounding, see 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), 19.
- ³²David Bohm actually suggested a variation of EPR that nonetheless kept with its aims. In 1964, John 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.
- ³³In 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 Inequalities," *Physical Review Letters* 49 (1982): 91-94. For a reasonably clear explanation of the Aspect experiments, see Gribbin, *Encyclopedia*, s.v. "Aspect experiment."
- ³⁴Salmon, *Four Decades*, 186.
- ³⁵Bohr, "Causality," 294. Werner Heisenberg agreed with Bohr. See Heisenberg, *Physics and Philosophy*, 44.
- ³⁶John 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.
- ³⁷K. 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.
- ³⁸Ernan 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.
- ³⁹Jan 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.
- ⁴⁰Arthur Fine, "The Natural Ontological Attitude," in *Scientific Realism* (ed. Jarrett Leplin; Los Angeles: University of California Press, 1984), 93.
- ⁴¹Norris, *Quantum Theory*, 1.
- ⁴²*Ibid.*, 195.
- ⁴³Plotnitski 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.
- ⁴⁴Richard 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.
- ⁴⁵*Ibid.*, 7.
- ⁴⁶*Ibid.*, 17-18.
- ⁴⁷Zohar and Marshall, 41-42.
- ⁴⁸*Ibid.*, 137.
- ⁴⁹*Ibid.*, 141. Zohar elsewhere indicates that religion is out and science and psychology are in as the new forces that 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.
- ⁵⁰Max Born, *Physics in My Generation* (2nd ed.; New York: Springer-Verlag, 1969), 142.
- ⁵¹*Ibid.*, 143.
- ⁵²Brian Greene, *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory*

- (New York: Vintage Books, 1999), 349.
- ⁵³Wheeler, "Law without Law," 189.
- ⁵⁴For an excellent and concise description of Wheeler's experiment, see John Gribbin, *Encyclopedia*, s.v. "delayed choice experiment."
- ⁵⁵John Archibald Wheeler, "Law without Law," in *Quantum Theory and Measurement* (ed. John Archibald Wheeler and Wojciech Hubert Zurek; Princeton: Princeton University Press, 1983), 194.
- ⁵⁶*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 Unsayable in Quantum Mechanics: Collected Papers in Quantum Mechanics* (New York: Cambridge University Press, 1987), 117.
- ⁵⁷P. W. Atkins, *Creation Revisited* (New York: W. H. Freeman & Company, 1992), 149.
- ⁵⁸Quentin Smith, "A Big Bang Cosmological Argument for God's Nonexistence," *Faith and Reason* 9 (1992): 217.
- ⁵⁹Quentin Smith, "Two Ways to Prove Atheism," sec. 1 [cited 26 July 2006]. Online: http://www.infidels.org/library/modern/quentin_smith/atheism.html.
- ⁶⁰William Lane Craig, "The Beginning of the Universe," in *Faith and Reason* (ed. Paul Helm; Oxford: Oxford University Press, 1999), 281.
- ⁶¹Keith Ward, *God, Chance and Necessity* (Oxford: Oneworld Publications, 1996), 40. For similar arguments, 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.
- ⁶²Kitchener, "Introduction," 15.
- ⁶³Laurikainen, "Wolfgang Pauli's Conception," 220-21.
- ⁶⁴*Ibid.*, 221.
- ⁶⁵Menas Kafatos and Robert Nadeau, *The Conscious Universe: Part and Whole in Modern Physical Theory* (New York: Springer-Verlag, 1990), 108-09.
- ⁶⁶*Ibid.*, 100.
- ⁶⁷K. 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.
- ⁶⁸Brian Greene, *The Fabric of the Cosmos: Space, Time, and the Texture of Reality* (New York: Knopf, 2004), 122-23.
- ⁶⁹Fritjof Capra, *The Tao of Physics: An Exploration of the Parallels Between Modern Physics and Eastern Mysticism* (4th ed.; Boston: Shambhala, 2000), 18.
- ⁷⁰Gary Zukav, *The Dancing Wu Li Masters: An Overview of the New Physics* (New York: William Morrow and Company, 1979), 62.
- ⁷¹Niels Bohr, *Atomic Physics and Human Knowledge* (New York: John Wiley & Sons, 1958), 19-20.
- ⁷²Laurikainen, "Wolfgang Pauli's Conception," 226.
- ⁷³Laurikainen, "Quantum Theory," 220.
- ⁷⁴Michel 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.
- ⁷⁵John Polkinghorne, *Science and the Trinity: The Christian Encounter with Reality* (New Haven, CT: Yale University Press, 2004), 5.
- ⁷⁶A. S. Eddington, *The Nature of the Physical World* (New York: Macmillan, 1928), 294-95.
- ⁷⁷G. E. M. Anscombe, "Causality and Determination," in *Causation and Conditionals* (ed. Ernest Sosa; Oxford: Oxford University Press, 1975), 79.
- ⁷⁸Arthur Peacocke, "God's Interaction with the World: The Implications of Deterministic 'Chaos' and of Interconnected and Interdependent Complexity," in *Chaos and Complex-*

- ity: *Scientific Perspectives on Divine Action* (ed. Robert John Russell, Nancey Murphy, and Arthur Peacocke; Vatican City: Vatican Observatory Publications, 1995), 281.
- ⁷⁹Arthur Peacocke, *Theology for a Scientific Age: Being and Becoming—Natural, Divine and Human* (2nd ed.; Minneapolis: Fortress Press, 1993), 157.
- ⁸⁰Greg Boyd, *God of the Possible* (Grand Rapids: Baker, 2000), 109.
- ⁸¹Norris, *Quantum Theory*, 146-47.
- ⁸²Karl Popper, *The Open Universe: An Argument for Indeterminism* (Totowa, NJ: Rowman and Littlefield, 1982), 126.
- ⁸³William G. Pollard, *Chance and Providence: God's Action in a World Governed by Scientific Law* (New York: Charles Scribner's Sons, 1958), 43.
- ⁸⁴*Ibid.*, 66.
- ⁸⁵Philip D. Clayton, *God and Contemporary Science* (Edinburgh: Edinburgh University Press, 1997), 193-94.
- ⁸⁶*Ibid.*, 194.
- ⁸⁷Jeffrey Koperski, "God, Chaos, and the Quantum Dice," *Zygon* 35 (2000): 546.
- ⁸⁸Peter E. Hodgson, "God's Action in the World: The Relevance of Quantum Mechanics," *Zygon* 35 (2000): 511.
- ⁸⁹*Ibid.*, 514.
- ⁹⁰John 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.
- ⁹¹*Ibid.*
- ⁹²Ruth Moore, *Niels Bohr: The Man, His Science, & the World They Changed* (New York: Knopf, 1966), 406-07.
- ⁹³Plotnitski, *Complementarity*, 76.
- ⁹⁴M. 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.
- ⁹⁵Faye, *Niels Bohr*, 216.
- ⁹⁶*Ibid.*
- ⁹⁷Laurikainen, "Wolfgang Pauli's Conception," 224.
- ⁹⁸Clifford 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), 171.
- ⁹⁹Bohr cited in Max Jammer, *The Philosophy of Quantum Mechanics: The Interpretations of Quantum Mechanics in Historical Perspective* (New York: John Wiley & Sons, 1974), 12.
- ¹⁰⁰Arkady 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.
- ¹⁰¹Herbert 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.
- ¹⁰²K. V. Laurikainen, *Beyond the Atom: The Philosophical Thought of Wolfgang Pauli* (Berlin: Springer-Verlag, 1988), 30.
- ¹⁰³Tongdong Bai, "Philosophy and Physics: Action-At-A-Distance and Locality" (Ph.D. diss., Boston University, 2004), 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.
- ¹⁰⁴*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.
- ¹⁰⁵*Ibid.*, 196.
- ¹⁰⁶For details on why Bohm's interpre-

- tation is problematic, see Howard, "The Copenhagen Interpretation," 141-50.
- ¹⁰⁷James 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.
- ¹⁰⁸J. P. Moreland, *Christianity and the Nature of Science: A Philosophical Investigation* (Grand Rapids: Baker, 1989), 28.
- ¹⁰⁹Trevor J. Pinch, "The Hidden-Variables Controversy in Quantum Physics," *Physics Education* 14 (1979): 50; Albert, *Quantum Mechanics*, 52.
- ¹¹⁰Paul 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.
- ¹¹¹Paul 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), 344.
- ¹¹²James 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. See James T. Cushing, *Theory Construction and Selection in Modern Physics: The S Matrix* (Cambridge: Cambridge University Press, 1987), 7. Mara 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." See Mara Beller, "Born's Probabilistic Interpretation: A Case Study of 'Concepts in Flux,'" 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), 249.
- ¹¹³Max Planck, *Where is Science Going?* (New York: W. W. Norton & Company, 1932), 204-05.
- ¹¹⁴Cushing, "Underdetermination," 276.
- ¹¹⁵John Bell, "Speakable and Unspeakable," 171.
- ¹¹⁶Heinz 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.
- ¹¹⁷*Ibid.*, 22.
- ¹¹⁸Karl Popper, *Quantum Theory and the Schism in Physics* (London: Routledge, 1982), 5-6. Michael Redhead, *Incompleteness, Nonlocality, and Realism: A Prolegomenon to the Philosophy of Quantum Mechanics* (Oxford: Clarendon Press, 1987), 51.
- ¹¹⁹David Bohm, *Causality and Chance in Modern Physics* (Philadelphia: University of Pennsylvania Press, 1957), x.
- ¹²⁰Albert Einstein, "Reply to Criticisms," in *Albert Einstein: Philosopher-Scientist* (New York: Tudor, 1951), 666.
- ¹²¹Jammer, *The Philosophy of Quantum Mechanics*, 257.
- ¹²²Ernan 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.
- ¹²³Heilbron, "The Earliest Missionaries," 219.
- ¹²⁴Raymond 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.
- ¹²⁵Tim Maudlin, *Quantum Non-Locality and Relativity: Metaphysical Intimations of Modern Physics* (2nd ed.;

Oxford: Blackwell, 2002), 240.

¹²⁶Abner 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.

¹²⁷Euan Squires, *The Mystery of the Quantum World* (Boston: Adam Hilger, Ltd., 1986), 132.

¹²⁸Norris, *Quantum Theory*, 35.

¹²⁹Kafatos and Nadeau, *The Conscious Universe*, 117, 75.

¹³⁰Ronald H. Nash, *Life's Ultimate Questions: An Introduction to Philosophy* (Grand Rapids: Zondervan, 1999), 248.

¹³¹John Hedley Brooke, *Science and Religion: Some Historical Perspectives* (Cambridge: Cambridge University Press, 1991), 19.

¹³²Nash, *The Word of God*, 81. See also, Stephen Wellum, "Postconservatism, 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 Kjos Helseth, and Justin Taylor; Wheaton, IL: Crossway, 2004), 187.

¹³³Douglas Groothuis, "Truth Defined and Defended," in *Reclaiming the Center*, 68-69.

¹³⁴Stanley L. Jaki, *The Savior of Science* (Grand Rapids: Eerdmans, 2000), 1.

¹³⁵*Ibid.*, 65.

¹³⁶Del Ratzsch, *Science and Its Limits: The Natural Sciences in Christian*

Perspective (Downers Grove, IL: InterVarsity Press, 2000), 136-37.

¹³⁷Vern S. Poythress, "Why Scientists Must Believe in God: Divine Attributes of Scientific Law," *Journal of the Evangelical Theological Society* 46 (2003): 112.

¹³⁸Nicholas Saunders, *Divine Action and Modern Science* (Cambridge: Cambridge University Press, 2002), 90.

¹³⁹Polkinghorne, *Science and the Trinity*, 79.