Quantum Theology beyond Copenhagen

with Mark Harris, "Quantum Theology beyond Copenhagen: Taking Fundamentalism Literally"; Shaun C. Henson, "What Makes a Quantum Physics Belief Believable? Many-Worlds among Six Impossible Things before Breakfast"; Emily Qureshi-Hurst, "The Many Worries of Many Worlds"; Elise Crull, "Interpretation Neutrality for Quantum Theology"; Wilson C. K. Poon and Tom C. B. McLeish, "Is There a Distinctive Quantum Theology?"; and Ernest L. Simmons, "The Entangled Trinity, Quantum Biology, and Deep Incarnation."

QUANTUM THEOLOGY BEYOND COPENHAGEN: TAKING FUNDAMENTALISM LITERALLY

by Mark Harris

Abstract. Theological engagement with quantum physics has, to this day, been dominated by the Copenhagen interpretation. However, philosophers and physicists working in the "quantum foundations" field have largely abandoned the Copenhagen view on account of what is widely seen as its troublesome antirealism. Other metaphysical approaches have come to the fore instead, which often take a strongly realist flavor, such as de Broglie-Bohm, or Everett's "Many-Worlds" interpretation. In the spirit of recent quantum foundations work, this article introduces a collection of studies aimed at taking quantum theology "beyond Copenhagen." The present article advocates a commitment to "quantum fundamentalism," which could resolve some of the enduring ontological problems faced by existing theological work with quantum mechanics, especially in discussions of quantum special divine action. Taking quantum fundamentalism literally would mean a departure from the Copenhagen interpretation, and the article suggests the need for a new research program to lay the groundwork in the natural theology of quantum foundations.

Keywords: Copenhagen interpretation; instrumentalism; natural theology; quantum fundamentalism; quantum ontology; quantum theology; special divine action

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Quantum Theology Beyond Copenhagen

The articles in this collection arose from two workshops (both entitled *Quantum Theology Beyond Copenhagen*),[1] which brought together physicists, philosophers, and theologians with the aim of exploring

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recent developments in the interpretation of quantum mechanics (QM),[2] and their relevance for Christian theology. The so-called "Copenhagen Interpretation" of QM (or just "Copenhagen" in this article) has been near-ubiquitous in theological engagements with quantum physics so far, reflecting the dominance of the Copenhagen perspective in the popular imagination, and the ease with which Copenhagen can be turned to theological ends. Not just in the popular imagination: the fact that most physicists in the very large mainstream areas of particle physics and condensed-matter physics work with a broadly instrumentalist approach to QM (of which more later) is consistent with the conclusion that the Copenhagen mindset is widespread in modern science too. The enduring popularity of Copenhagen does not, however, extend as far as that research field most concerned with quantum interpretation, namely the "quantum foundations" field. Instead, philosophers and physicists working here on the conceptual underpinnings of QM have largely abandoned Copenhagen on account of what is widely seen as its troublesome antirealism. Other metaphysical approaches have come to the fore instead. Realist interpretations (such as de Broglie-Bohm, or Everett's "Many-Worlds" interpretation) and information-theoretic perspectives (such as QBism) have tended to dominate recent quantum foundations work, but there are many other readings of quantum theory under active discussion; it is fair to say that the quantum foundations field is not currently short on imagination, even if it is short on a consensus.

To date, there has been some theological engagement with alternatives to Copenhagen, but it has been limited. For instance, David Bohm's metaphysics of "implicate order" (Bohm 1980) has been cited by some theologians interested in constructing holistic views of creation (e.g., Keller 2015), but the Copenhagen view has remained as the default setting for quantum theology. Our workshops—and these articles—are early attempts to see just what might be learnt theologically by wandering in the expanding territory of quantum foundations beyond Copenhagen. We have come to realize that, not only are there many potentially fresh research directions here for the science-and-theology field, but theologically minded work might itself make positive critical input into quantum foundations. After all, since the proliferating interpretations of QM are largely equivalent in empirical terms—they cannot readily be distinguished between experimentally and therefore cannot be tested in the laboratory—then these interpretations must be evaluated on metaphysical grounds instead, where theology has proven credentials.

The other articles in this collection take some of these first steps beyond Copenhagen, testing the theological potential of recent perspectives in quantum foundations. The best-known such perspective—Everett's "Many-Worlds" Interpretation—is also probably the most outlandish in everyday "commonsense" terms, a point which explains its chequered reception history, as Henson's article makes all too clear. Suffering from skepticism and neglect among physicists for decades, Everett's is now one of the dominant realist interpretations in the quantum foundations field. This renaissance is at least partly down to the fact that Everett's interpretation is the clearest metaphysical outworking of "quantum fundamentalism" (the subject of my own article). But as Henson explains, this renaissance also illustrates the social dynamics that underlie the ways in which challenging metaphysical worldviews come to be accepted, whether those worldviews are scientific at heart (as in Everett's interpretation) or theological (as in ideas about the being of God). This is not to make light of the challenges, and Qureshi-Hurst looks in detail at the formidable philosophical, ethical, and theological obstacles raised by Everett's interpretation; theologians and philosophers need to engage with these obstacles, she warns, if theistic worldviews are to retain their coherence in the Many Worlds scenario. An altogether different approach is demonstrated by Crull, who looks at what may be gained theologically by adopting a position of strict neutrality toward the various interpretations. Her point is that, once we take quantum decoherence seriously, then quantum science (in its largely interpretation-free "textbook" form) already provides theological (and *realist*) promise without the need to make difficult metaphysical decisions concerning quantum ontology. McLeish and Poon make a similar point about decoherence, but argue more widely against theological claims for the distinctiveness of QM, especially if those claims seek to establish the special status of the observer in order to promote idealist theologies. For one thing, McLeish and Poon point out that classical statistical mechanics can be mapped onto QM, thus providing complementary ways of looking at the observer-dependence of science. Instead, both QM and classical statistical mechanics point to a participatory theology of science, they suggest, an observation which has, thus far, barely been explored theologically but which holds significant promise for constructive dialogue between QM and theology. The last article in this collection illustrates what can be gained by embarking on such constructive work. Thus, Simmons makes a positive case for engaging with decoherence and "quantum Darwinism," suggesting that the science provides powerful new analogies in Christology and Trinitarian theology.

Clearly then, there are many reasons to look at perspectives beyond Copenhagen when trying to make theological sense of QM. This present article provides one more. I argue for a commitment to "quantum fundamentalism," respecting a widespread view among scientists who work with QM, and a widespread view in the quantum foundations area. Such a commitment could resolve some of the enduring ontological problems faced by existing theological work with QM, especially in discussions of quantum special divine action (QDA). Taking quantum fundamentalism literally would mean a departure from the Copenhagen interpretation though, or at least a departure from the way it has been used thus far in QDA.

Taking Fundamentalism Literally

What has QM to do with fundamentalism? The answer is: a great deal, although I should say from the beginning that by "fundamentalism" I do not mean the religious kind associated with scriptural literalism and conservative social practices, as in Young-Earth Creationism, or *The Handmaid's Tale*. Instead, by "fundamentalism" I am referring to a conviction about the natural sciences' ability to probe and describe what might be most fundamental to our natural world: nature's most basic physical *ontology* (by which I mean the way that nature is structured and functions at its most universal and comprehensive physical level). Nancy Cartwright was famously scathing of such scientific fundamentalisms in her well-known book of 1999, *The Dappled World*, where she promotes the view that scientific laws should be seen, not as universal and exceptionless, but as patchwork and highly context dependent. Instead of fundamentalism, she wants to promote pluralism in the sciences. But, *pace* Cartwright, fundamentalism is a surprisingly seductive and powerful belief, especially in physics, and especially when QM is in view.

It is no understatement to say that QM is the most successful theoretical framework in the entire natural sciences, to date. QM has transformed our view of molecular, atomic, and subatomic matter, and it forms a basic framework for research into the properties of all kinds of matter across diverse scientific areas, from particle physics through condensed matter physics, chemistry, materials and earth science, to molecular biology and many other natural sciences. Many modern technological innovations are reliant on the science of QM, not least the entire electronics and telecommunications industries. Despite countless tests, QM has always proved to be correct, and it provides the basis for some of the most precise predictions in the whole of science. In one celebrated example (the anomalous magnetic moment of the electron), *theoretical calculations match experiment to eleven decimal places* (Aoyama et al. 2018). This is astonishing, and it is no wonder that most physicists believe physical reality to be altogether and wholly quantum. Stephen M. Barr (2021, 504)—a working physicist writing here in a science-and-theology context—speaks for many when he opens his discussion of QM and divine revelation with a stunning statement of the primacy of QM for understanding all physical phenomena:

> FIRST, quantum mechanics is not just a theory of this or that physical phenomenon or realm of phenomena; it is an overarching framework for all of physics. Its principles (the "postulates of quantum mechanics") apply to all physical phenomena and therefore, strictly speaking, all physical phenomena are "quantum phenomena."

Similar statements can be found everywhere in the popular science literature which focuses on physics. Strangely, this sentiment has only recently found a name for itself: some researchers in the quantum foundations field have begun to speak of it as "quantum fundamentalism." This is how Henrik Zinkernagel (2016, 2; cf. Zinkernagel 2011; Faye 2019, 235) defines the term:

> Quantum Fundamentalism. Everything in the universe (if not the universe as a whole) is fundamentally of a quantum nature and ultimately describable in quantum-mechanical terms.

Although one rarely hears the term outwith the quantum foundations field, I will maintain in this article that quantum fundamentalism is a widespread hunch in mainstream physics, and that it has important but subtle implications for theological engagement. For, in case one is tempted to dismiss quantum fundamentalism as of relevance only to "fundamental" physicists, monotheists also have a stake in it when it comes to questions about how God might be said to underpin the physical world and to work in it.

First, it is usually understood in theological circles that talk of "creation" means our natural physical world and nonphysical entities which emerge from it such as mind and culture (give or take questions about *supernatural* created entities like souls, angels, etc.). But to connect creation talk with the *physical* world as a package deal instantly means that assumptions are being made about the laws of the physical sciences and their ability to define, describe, and demarcate this world for us as a category for creation talk. Hence, what kind of laws do we have in mind here? Before the twentieth century, Newtonian physics informed the entire worldview of physical cosmology, but we now know that such physics is an approximation to a more complete relativistic view. We hope that, in time, this latter view will be combined with QM to form a fully comprehensive account of natural physical laws at a still more basic level. It is, therefore, inescapable that talk of creation as a package deal will at some point need to negotiate its attitude to fundamental physical conceptualizations of reality.

Second, if we were to hit upon a scientific description of the physical world that appeared to be so elemental and wide ranging in explanatory power as to underpin every other scientific discipline, then it would be tempting to suppose that we might be nearing metaphysical "bedrock," as it were, that we might be privileged to a glimpse of the natural foundation on which all of God's creative and providential activity in the cosmos is built. And perhaps a scientific explanation of such unrivalled primacy might even be taken as indicative of the membrane between the natural and supernatural (the "causal joint"), through which God's creative and providential activity passes into the created world. At any rate, if it is meaningful to speak of a single scientific explanation in such exalted terms then we would presumably have found a case where the physicist's fundamentalism and the theist's fundamentalism coincide. According to some prominent voices in the science-and-theology field, we have indeed found such a case where these two fundamentalisms coincide: QDA, where QM provides the means by which God works in the natural world, exercises providence, and answers prayers.

The basic problem for theism—which QDA tries to address—goes like this. Classical Newtonian physics is deterministic, to such an extent that we might reasonably expect every physical cause and effect in the universe to be uniquely determined by the laws of nature. Or at least, this is the conviction captured by the metaphysical thought experiment of Laplace's Demon, where the future is entirely fixed and (in principle for the Demon) altogether knowable. How can God influence the course of such a rigid and iron-bound world? Is there such a thing as human free will if the future is fully determined by the past? These are long-standing and (in)famous problems. Happily, the development of QM in the twentieth century has provided a solution, at least in its Copenhagen guise, since QM is indeterministic: we cannot use the quantum laws of nature to determine the future with full certainty since such laws only predict probabilistic outcomes. Hence, if classical (especially Newtonian) physics seemed to be closing the doors on God's influence in the world, then quantum physics, which we now believe is even more fundamental than Newton, is opening those doors again; QDA therefore provides an opportunity to defend one of the fundamentals of theism, that God can work in our world and answer our prayers. Or so the story goes.

I, however, am unsure that these two fundamentalisms—the physicist's and the theist's—coincide in QDA, at least not if our metaphysics is informed by the Copenhagen interpretation. I will suggest in this article that these two fundamentalisms compete, and—since this article is a prolegomenon to a more detailed account (hopefully to be published as *Theology and the Quantum World*)—I will gesture toward some alternative solutions at the end. First, I will outline what I mean by "the Copenhagen Interpretation," before turning to Eddington's fable of "the two tables" to show why there is a problem of competing fundamentalisms. Then I will examine a rhetorical device which is widespread in quantum physics—which I call the "rhetoric of the two worlds"—and will develop this in my main theological test case of QDA. At the end, I will suggest the need for a new kind of approach to quantum fundamentalism—not just to new models of QDA—which I characterize as a natural theology of quantum foundations.

The Copenhagen Interpretation

It is often assumed that there is a single definitive version of Copenhagen (*the* Copenhagen interpretation). Historical work of recent decades has questioned that assumption, arguing that it does not reflect any settled view of the founding figures of QM in the 1920s and 1930s; indeed, these characters were in deep disagreement on many matters of interpretation (Faye 2019). Instead, the notion that there is a unitary version of Copenhagen seems to have arisen largely through the massive cultural authority gifted to Werner Heisenberg's Gifford Lectures of 1955–56, which include a chapter entitled "The Copenhagen Interpretation of Quantum Theory" (Heisenberg 1990). Arguably, Heisenberg "invented" the Copenhagen interpretation (Howard 2004), which is why, all too often, contemporary accounts of "the Copenhagen interpretation" are actually presentations of Heisenberg's view. Nevertheless, it is fair to say that the founding figures who are usually included in the broad Copenhagen "school" (including Heisenberg, and others such as Bohr and Pauli) all agreed that the special problems introduced by *measurement* (observation) of a quantum system force the need for a strong metaphysical caution.

The infamous example of Schrödinger's cat illustrates the issues well enough. In this thought experiment, measurement is basic to determining reality. Until we make a measurement of a quantum system—such as the eponymous cat in a box with a lethal device triggered by a radioactive decay, or (better, because more realizable) an electron travelling through space before it interacts with a double-slit experiment—the system's wavefunction (i.e., the system's mathematical representation in the quantum formalism) represents the system as being in a *superposed* state, that is, one in which all possibilities are simultaneously combined. If we want to know whether the cat is alive or dead, or where the electron is, we must make a measurement. And according to the formalism, at that point the wavefunction of the system collapses into one possibility and the cat is observed as being either alive or dead, or the electron is observed as being in a particular place. The formalism allows us to calculate the probabilities of what we will observe of the state of the cat or the whereabouts of the electron before we make our observation, but full certainty is not open to us until the point of measurement, when the indeterminacy surrounding the system becomes determinate. In other words, before the wavefunction has collapsed (i.e., before we have made our measurement), the wavefunction—taken literally—represents the cat as being both alive and dead at the same time, or the electron as being in several places at once. But what is the truth of the matter before measurement? Does our inability to pronounce on the state of the cat or the electron reflect the *ontology* of the quantum state—that the cat is truly both alive and dead at the same time, that the electron is truly indistinct and smeared-out in space until measurement—or is it more of an *epistemological* limitation, a basic constraint on the ability of our experimental methods to reveal nature in its fullness? Opinions vary on this question within the broad school of physicists historically associated with Copenhagen, although Heisenberg (1990, 173–74) famously seemed to take the ontological stance when he referred to the quantum state as residing in an "ontology" of "potentiality," while simultaneously combining it with a decidedly antirealist twist, saying that the quantum state is "not as real" as everyday phenomena. At any rate, the typical Copenhagen approach is to be cautious before pronouncing on the unobserved properties of quantum systems. This metaphysical caution introduces an inevitable antirealism, or at least a kind of instrumentalism, to which I will return shortly.

But first, what might it mean to speak of a quantum ontology in the first place, and how does it relate to our everyday assumption of a real ontology on the level of cats and dogs, people, tables and chairs? Arthur Eddington's (1929, *xi–xv*) fable of the two tables is an excellent way of seeing the issues here; it appears at the beginning of his own Gifford Lectures, originally delivered in Edinburgh in 1927.

One Table or Two?

Eddington has two tables. One is a commonplace table—manifestly and substantially solid—capable of supporting his weight if he leans on it. His other table—his *scientific* table—is extremely insubstantial, consisting mostly of empty space, but with many electric charges rushing around in it, while they constitute "less than a billionth of the bulk of the table itself," he points out (Eddington 1929, *xii*). For all that, Eddington's scientific table is still capable of supporting his weight:

> Notwithstanding its strange construction it turns out to be an entirely efficient table…If I lean upon this table I shall not go through; or, to be strictly accurate, the chance of my scientific elbow going through my scientific table is so excessively small that it can be neglected in practical life. (Eddington 1929, *xii*)

If he lays a sheet of paper on the scientific table (or leans on it with his scientific elbow), the electric particles continually hit the underside of the paper (or his elbow) and support it in place. As far as the practicalities of supporting a grown man writing on a piece of paper are concerned then, the second table functions very much like the first. And yet, most of this second table is composed of empty space, while the first is made of a solid and rigid substance.

Of course, Eddington's point is that these two tables are one and the same table, but interpreted (perceived?) from different perspectives (epistemologies): the first from that of everyday human experience, the second from the view of the physicist in the laboratory. But these two epistemologies are not equal in stature, according to Eddington. The first—where the table is solid and substantial—is, in effect, a convenient fiction created by our senses, while the second—where the table is largely empty space—is the true table, "the only one which is really there," says Eddington (1929, *xiv*). And yet it is hard to escape the conviction—at least with our everyday experience in view—that the first table does indeed have a tangible and substantial reality of its own. This conviction bears upon the physicist as much as everyone else, since Eddington tells us that the physicist always begins with that first perspective (the solid everyday table) before journeying through the second "foreign territory," and in the end returns to the first perspective (Eddington 1929, *xiv–xv*). And since our perception of the first table (our everyday experience mediated by our consciousness) is unrelated to how we perceive the second (by means of scientific reasoning and technical experimentation), there is nothing that physics can do of itself to dissuade us of the reality of the first table. In other words, Eddington might have persuaded himself that the second table is the only *true* table, but the physics cannot confirm it to be the case. He is, in effect, constantly drawn toward the conflicting position where each of the tables represents an ontology in its own right—each table is real—although in his most sober-minded (scientific) moments he believes that only the second is the real table.

Quantum Fundamentalism and the Rhetoric of the Two Worlds

Eddington's commitment to the truth of the scientific table shows that he is a quantum fundamentalist, a commitment shared by the majority of working physicists. But it is an uneasy commitment, as he explains, since his everyday experience teaches him the exact opposite, that it is only the solid, substantial table which is real. For modern working physicists this unease is exacerbated (or at least, further complicated) by the fact that the dominant Copenhagen approach to QM forces a degree of antirealism on our attitude to the quantum state. We may be quantum fundamentalists, but we are (most of us) antirealist quantum fundamentalists, or at least, instrumentalist quantum fundamentalists. How can such contradictory positions be coherent?, you might ask. How does any of this make sense?, you may also be asking. Indeed. At this point, I need to explain the ubiquitous rhetoric built into Copenhagen-minded discussions of the quantum measurement problem, a rhetoric which seeks to allay the complicated unease; this is the rhetoric of the two worlds, the quantum and the classical.

As I said earlier, the Copenhagen approach typically shows a reluctance to speak of unobserved quantum entities or properties in realist ways; this antirealism works itself out in a kind of pragmatic instrumentalism in mainstream physics (i.e., areas of physics outwith quantum foundations). In fact, quantum instrumentalism is widespread in most mainstream areas of physics that rely on QM (such as my own, condensed matter physics). Quite simply, we have discovered that the mathematical quantum formalism is highly effective as a set of tools for predicting the results of measurements without requiring us to take a firm metaphysical stance on what is really going on. And of course, there is always the celebrated authority of the Copenhagen founding figures such as Bohr and Heisenberg to back up our instrumentalism if we are ever tempted to wonder about the ontologies behind our equations and measurements. But we rarely wonder, at least out loud. There is an infamous joke in physics about the strict need to maintain a neutral disinterest toward the distracting metaphysical questions raised by QM: "Shut up and calculate!"

In our heart of hearts, few working physicists are entirely persuaded by this routine instrumentalism; most appear to temper the instrumentalism of our daily work with a deeper-seated but aspirational realism: a gut instinct that there is a quantum reality out there, even if we must remain rather cautious not to say too much about it for the time being. Such an attitude is consistent with the widespread conviction of quantum fundamentalism, which—in common with other metaphysical convictions—cannot be demonstrated empirically by physics, but is consistent with the stunning success of QM across physics and other branches of the natural sciences. Remember: eleven decimal places.

And yet, to repeat, in spite of all this certainty about the fundamental quantum nature of the universe, working physicists are bound professionally to an everyday instrumentalism with respect to QM. We are being pulled in two directions, and our quantum realism must remain an aspiration while we get on with our day jobs. A highly revealing sign of the aspirational realism adopted by many physicists in the face of their everyday instrumentalism can be seen in the ubiquitous rhetoric of "two worlds" (e.g., Gerry and Bruno 2013, 1–2; Penrose 2016, 138–140; McDonnell 2017, 242; Norsen 2017, 63, 154; Becker 2019, 276; Laloë 2019, 22). This rhetoric is to be found in quantum textbooks, popular introductions, and in fact almost everywhere that the measurement problem comes into view (outwith discussions of *realist* interpretations of QM, where the two-worlds rhetoric is unnecessary). In the rhetoric, the measurement problem is cast in terms of two ontologies/worlds/realms, the classical and the quantum. Effectively, this form of language allows us to speak about the quantum state in realist terms—it is a "world" after all—while acknowledging that there is no straightforward connection with our everyday classical experience (which appears much more real to us).

To summarize so far: We have a strange dilemma at the heart of the measurement problem as it is typically described within the Copenhagen perspective or any instrumentalist perspective which foregrounds the quantum formalism over possible ontologies. The problem is posed in terms, not so much of tables, but of the relationship between classical physics and quantum physics, and it frequently uses the two-worlds language to do so. The first table stands for the world of classical physics, the second for the quantum world. The classical world is the everyday macroscopic world which humans inhabit, where we believe that—in physical terms, at least—we can speak realistically of a physical entity possessing determinable properties quite apart from our observations of it, where it is therefore meaningful to distinguish subject from object, and cause from effect; where we are able to speak of one event following another to discern the flow of time, and so on. That is the classical world. But of the quantum world we can know nothing until we make a measurement, and before that point we have no meaningful way of posing the distinction between subject and object, of describing cause and effect, of ordering events one after another, nor even of speaking about an unobserved "event" as such. And yet, as quantum fundamentalists we believe that the quantum world is the only true physical world, while the classical world is (in ontological terms) a convenient fiction, even if it may be an astonishingly persuasive fiction in our everyday lives, and capable of great predictive power in the guise of classical physics.[3]

The rhetoric of the two worlds allows working physicists to maintain an uneasy truce between the epistemic pull of our physics on the one hand, and the ingrained, easy familiarity of everyday life on the other. We speak of quantum and classical as though we are dealing with two effective universes connected only by the mysterious portal of "measurement," but this talk is merely for convenience. When pressed, we will probably maintain the ontological truth of the single quantum world, while making vague gestures toward decoherence to account for the apparent reality of the classical world. But by and large we do not take the rhetoric of the two worlds literally in our work because we simply do not need to. For the purposes of getting on with the physics, a broad and generous instrumentalism works just as well in both worlds, quantum and classical.

So much for the fundamentalism of the working physicist. What about that of the theist, and especially that of the theist who wants to incorporate QM into their fundamentalism? Now we find that the two-worlds language is less of a convenient rhetorical device, and more of a difficult problem with real ontological force. Such is my argument about QDA, and my suggested solution is for the theist to adopt a full-blooded quantum fundamentalism.

Quantum Special Divine Action

QDA is perhaps the longest-running science-and-theology research program of modern times, traceable back to the 1930s (i.e., the early years of QM), according to Nicholas Saunders' magisterial and critical overview (Saunders 2002, 94–126). By far its sharpest creative focus came in the collaboration between the Center for Theology and the Natural Sciences (Berkeley, California) and the Vatican Observatory, which operated between 1988 and 2003, and which produced five edited collections of essays on special divine action. Following the title of Wesley Wildman's later response to Saunders (Wildman 2004), this work is widely referred to as the "Divine Action Project" (DAP). The DAP covered a huge scope of scientific, philosophical, and theological questions around special divine action, but it is its attention to QM which has become particularly significant in later appraisals of the DAP (as indeed it was QM which received special prominence in Wildman's defense of the DAP against Saunders).

Scientific determinism and indeterminism were key areas of concern for the DAP. If it is true that nature is shackled in the iron-bound grip of deterministic laws, then God's special action can only be *interventionist*—breaking-in to interrupt natural processes from the outside, as it were—something which many members of the project were keen to avoid. There is a simple issue of theological consistency at stake, as Wildman (2004, 38) explains:

> [T]he DAP project tried to be sensitive to issues of theological consistency. For example, the idea of God sustaining nature and its law-like regularities with one hand while miraculously intervening, abrogating, or ignoring these regularities with the other hand struck most members as dangerously close to outright contradiction. Most participants certainly felt that God would not create an orderly world in which it was impossible for the creator to act without violating the created structure of order.

Hence, these participants were keen to explore *noninterventionist* models of divine action, which brought indeterministic causal mechanisms in the natural sciences to prominence. John Polkinghorne's advocacy of chaos theory for divine action is one well known example, as is Arthur Peacocke's top-down emergentist scheme. But QM drew a wide share of the attention, and four DAP authors published constructive appraisals of noninterventionist QDA which exploited quantum indeterminacy: Nancey Murphy (2000), Thomas F. Tracy (2000, 2001), George Ellis (2000; 2001), and Robert J. Russell (2001). There are differences between these various models, but there is a strong emphasis on God's action through quantum indeterminacy around quantum "events" and wavefunction collapse (Murphy 2000, 343, 346, 354, 356; Tracy 2001, 255, 257–81; Russell 2001, 296–97). Of these authors, Russell's work is of special interest, since he has been developing his ideas since the 1980s and has published extensively on QDA ever since, right up to the present day (Russell 2022). As a result, Russell's account of QDA is the most comprehensive of all, and although it has undergone developments it has remained remarkably consistent in its main details; I will outline his model briefly as the gold standard of QDA, using his lucid exposition of it in the authoritative *Oxford Handbook of Religion and Science* (Russell 2008).

Russell terms his model with the acronym QM-NIODA: Quantum Mechanics (or Quantum Mechanical)-Non Interventionist Objective Divine Action. His starting point is Heisenberg's version of Copenhagen, which Russell takes to be a commanding statement of the ontological indeterminism of nature, as depicted by QM. I will let Russell (2008, 586) speak for himself at this point:

> While the Schrödinger equation applies deterministically to the propagation of the wave function and includes efficient causes in the form of potential energies (representing forces at work in nature), during a quantum event, or "collapse of the wave function," the Schrödinger equation does not apply, and there is no efficient natural cause that brings about this event. It is this interpretation which forms a promising basis for what I will call "QM-NIODA." My central thesis is that God acts objectively and directly in and through (mediated by) quantum events to actualize one of several potential outcomes; in short, the collapse of the wave function occurs because of divine and natural causality working together even while God's action remains ontologically different from natural agency.

Russell has defended and expanded details of this proposal at great length in his work, but for my purposes this short passage points to the important idea, as follows. Nature is ontologically indeterministic, he believes, which means that there is no efficient cause in the Schrödinger dynamics to determine the outcome of quantum events or wavefunction collapses (two terms for one thing: what are often called "measurement outcomes" in the Copenhagen approach); instead, the outcome of such things is fundamentally stochastic. Therefore, God acts in tandem with a quantum event such that a *particular* outcome is realized out of the range of possibilities represented by the wavefunction evolving according to its Schrödinger dynamics. As Russell explains over the page: "God acts together with nature to determine which quantum outcome becomes actual; God can know which potential state will become actual, since *God causes it to become actual*! In essence, quantum indeterminism is the result of it being God, not nature, which determines the outcome" (Russell 2008, 587, emphasis his). If I may paraphrase Russell, determinate things happen in nature because God determines them out of the frothing sea of quantum indeterminacy.

Russell's model of QDA has received many critical appraisals over the years, and he has always responded with grace and patience. Indeed, his writings dominate the QDA literature, and the science-and-theology field owes him a great deal for his willingness to explore this classic theological and scientific conundrum with such nuance, all the while maintaining the kernel of the idea presented in the previous paragraph. Moreover, for a theist like myself, Russell's QDA is an attractive affirmation of God's universal creative and providential immanence. But for a working physicist like myself, I have to admit that something does not quite add up, something that (as far as I am aware) has gone under the radar in the extensive QDA literature so far. That something concerns QDA's effective transformation of the two-worlds story into what I refer to as "two worlds fundamentalism."

Two-Worlds Fundamentalism

Recall that the two-worlds story is a rhetorical device in the Copenhagen/instrumentalist version of QM that is widespread in mainstream physics. We do not really believe that there is an entire quantum world which is distinct in itself, joined to our classical world only by the portal of measurement (whatever that might be in physical terms; it helps not to question too deeply). But the rhetoric of the two worlds allows us to bypass the discomforting antirealism of the quantum measurement problem in its "textbook" form (i.e., taking the classic Copenhagen/instrumentalist stance where we are agnostic or indifferent to questions of quantum ontology). Of course, the rhetoric is just a convenient form of language; it does not actually negate the antirealism inherent in our stance. But QDA introduces a difficult question at precisely this point. What happens when the two-worlds rhetoric is made *real* for theological purposes, when both classical and quantum worlds are equally real but infinitely different, joined only by the portal of "measurement"? And where is God in all this?

Let me unpack those questions. The models of QDA under consideration all make a strong commitment to quantum indeterminacy so as to mitigate against the problem of divine interventionism; nature must be open so that God can work in and with it. Hence, realist interpretations of QM are, by and large, not considered as strong candidates for QDA on account of their determinism.[4] And Russell is explicit here, making Copenhagen a key starting point for his model of QDA, since he understands Copenhagen as indicating that nature is ontologically indeterministic. But as we have said, Copenhagen is—like the "shut up and calculate!" school with which it is so closely connected—expressly agnostic about quantum ontology, to the point of antirealism. Peter Hodgson, discussing theological use of QM, objected to the Copenhagen interpretation on these very grounds: "the Copenhagen interpretation is contrary to the Christian belief in a real world created by God" (Hodgson 2005, 157). Hence, by placing God's *objectively real* activity (remember, NIODA) in and with nature at the quantum level, what Russell's model of QDA is actually doing (and possibly the other models too) is converting Copenhagen into a *realist* model of QM. In effect, QDA takes the two-worlds story and treats it, no longer as a convenient rhetorical device, but as a fully realist account of the God-world relationship instead. Both quantum and classical worlds are now fully as real as each other,[5] so that the real God can work in and with indeterministic (quantum) nature and thereby influence the deterministic (classical) world. Crucially, this step also means that quantum and classical worlds are literally and incommensurably distinct, connected only through the portal of "measurement." I refer to this position (the worldview of QDA, if you like) as "two worlds fundamentalism."

At this point, the question arises of how God's action causes a transition from the quantum to the classical world at a "measurement," or in other words, how the wavefunction collapses to produce a determinate state. This question raises the related problem area of what exactly is a "measurement" in the first place, and how does it relate to the supposedly ubiquitous quantum "event." Does a "measurement" only occur when a human is watching, or can it happen "in the wild," as it were? These have been long-standing sore points in the realist/antirealist controversy around the foundations of QM for generations, and they have certainly been raised in the QDA area before (including by Russell 2018, 142–44), although to my mind without clear resolution (e.g., Saunders 2002, 139–44; Wegter-McNelly 2006, 104). This is not the place for me to enter into this complex debate about "measurement," since it requires a whole new article. I simply want to pursue a related question here, which is how God's action influences a measurement outcome in QDA. In spatial terms, we could think about this particular question as a search for the whereabouts of God in two-worlds fundamentalism. The picture of QDA as it stands would seem to place God's influence firmly in the quantum world, and certainly not in the classical world where all is determined. It is possible, however, that God is nowhere.

Where Is God?

This issue of the whereabouts of God in two-world fundamentalism has, in fact, had some attention in QDA circles (although not in so many words), where it has been framed as the question of whether God causes measurement processes (by actively driving wavefunction collapse), or whether God somehow influences the outcomes of naturally occurring measurement processes. Again, this is a complex area beyond my precise remit, but the answer has emerged from Wegter-McNelly (2006, 100–101) and Russell (2018, 143–44) that there are two distinct "ideas" in a measurement: the collapse, and the probabilistic outcome. God cannot be involved in the former, goes the reasoning—since that would seem to constitute an intervention—but rather in the latter. To my mind this proposal is problematic, since it implies that the two "ideas" correspond to two distinct and real physical processes in a measurement (or at the least, two objective components to a measurement). But according to the standard construal of measurement in the quantum formalism, a measurement is a monolithic transition which cannot be split into two physical components or processes (as though one part was in the quantum world and the other in the classical). In fact, a measurement is not even a transparent physical mechanism as such in the formalism (insofar as it could be further broken down and analyzed into more basic physical terms); instead, measurement is a postulate, a "given": it is undefined and primitive in the description of the wavefunction collapse (Margenau 1958, 23; Wallace 2012; Barrett 2019, 105). We can see this easily in the formalism: the wavefunction collapses according to the Projection Postulate (one of the five basic postulates of QM), thus accounting for the indeterminacy in the measurement outcome. The idea here is laid out in all of the usual QM textbooks, but for my purposes it is summarized concisely by Cushing in one of the DAP volumes (Cushing 2001, 101):

$$\psi = \sum_k c_k \psi_k \rightarrow \psi_j$$

At a measurement, the quantum wavefunction (ψ), with its full $3k$ dimensionality in the configuration space of the quantum world collapses instantaneously and stochastically to the observed eigenstate, ψ_j, in our three-dimensional world, with the probability $|c_j|^2$. There is no more detail hidden away in the projection postulate; this is it. Hence, the realist may "want" to view a measurement in terms of two objective physical happenings to the system—such that God could work in one and not the other—but the standard quantum formalism provides no support for such a solution (Isham 1995, 175–76). Therefore, any model of QDA with such realist aspirations is going beyond the standard formalism on which these Copenhagen-flavored models of QDA are based in the first place.[6] A further related point that arises with these models is that since "measurement" is primitive—it is a portal but not a physical "where" in the sense of an ontological component to two-worlds fundamentalism—it is difficult to see where God can be said to play a part in influencing the physics of either world. God's action appears to be nowhere in ontological (real) terms.

The upshot of these considerations is that, upon close examination of two-worlds fundamentalism, God's influence through QDA seems to vanish.

Conclusions

At first glance, my main point here has been critical, to examine QDA from the perspective of the working physicist, who is immersed in the Copenhagen/instrumentalist approach to QM, but who finds its theological application to QDA baffling upon close examination. I have put this in terms of the rhetoric of two worlds—quantum and classical—and I have suggested that QDA turns this rhetoric into reality; hence, the position that I have referred to as "two worlds fundamentalism." My reading of the situation is that God appears to vanish from our everyday world (the classical world) in two-worlds fundamentalism, and while it is possible that God's active presence might instead be found in the quantum world—a world which is quite distinct and separate (ontologically speaking) in this scheme—God might instead be in the portal of "measurement," which raises even more questions of whether God's influence is anywhere at all. As a result, I am not convinced that two-worlds fundamentalism offers a watertight framework for theistic divine action at present, since such a framework (if it is to incorporate God's action in and with nature) should include meaningful ontological opportunities (physical locations in the cosmological scheme of worlds, if you like) for God's work.

On closer inspection, I hope that my positive point standing behind all this should now begin to emerge, which is the following tentative suggestion. Instead of two-worlds fundamentalism, QDA should move beyond Copenhagen to engage more comprehensively with the framework of quantum fundamentalism. What might this framework have to offer theologically? It is difficult to say at the moment, because there has been so little theological work on the many realist approaches which have flourished in the quantum foundations world over the past couple of decades. The DAP outlined some of the concepts and challenges, but these approaches were largely considered unsuitable for further development in light of the promise offered by Copenhagen at the time. I suggest that the flourishing of quantum foundations offers new promise for QDA beyond Copenhagen. Crull's article in this collection provides a starting point for QDA within the quantum fundamentalist viewpoint, without any need to adopt a particular metaphysical interpretation at all. But it is also worthwhile engaging with the interpretations, I would suggest. Of course, these interpretations bring difficult challenges, as Qureshi-Hurst's article makes all too clear for Everett's interpretation. But one of the first steps could be to set aside the development of concrete models of QDA for a future date, and to look at the frameworks in depth first of all, as I did above with the rhetoric of the two worlds for Copenhagen. What this would require would be the development of a natural theology of quantum foundations. At the moment, work in natural theology is firmly situated in the common-sense world of classical physics, and so it tends to assume that our everyday human experiences of flowing time, of causation, of local influence, of subject-object distinctions all reflect the fundamental ontology of the created world. But taking quantum fundamentalism into natural theology would mean asking what theological sense could be made by adopting entire quantum ontologies. We would find ourselves questioning our common-sense views of time, of cause-and-effect, of local influence, of objectivity on theological grounds as well as physical. The realist interpretations are highly challenging from these common-sense points of view. Can they be baptized, and what would it mean for our traditional theological concepts of creation, providence, soteriology?

I do not know the answers to these questions, yet. But my recommendation to the science-and-theology field is that quantum fundamentalism is one kind of fundamentalism that needs to be taken seriously.

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Notes

1. The workshops took place in Edinburgh (September, 2021), and in Oxford (June, 2022) in the UK.
2. Note that I am using the term "quantum mechanics" (QM) as a catch-all for all contemporary branches of quantum theory and quantum science, whether they are relativistic (such as quantum field theory) or nonrelativistic.
3. We now realize that quantum decoherence provides a convincing way of relating the two worlds in practice, while maintaining the primacy of the quantum ontology over the classical. See Crull's article in this collection.
4. But note Alvin Plantinga's (2008) proposal to examine spontaneous collapse approaches (i.e., the Ghirardi-Rimini-Weber interpretation, widely known as "GRW"). These have the advantage of being both realist and indeterministic, but they introduce difficult ontological challenges around the point that there is no classical "world" in GRW, a point which Plantinga does not investigate. I hope to say more about this in my forthcoming book, *Theology and the Quantum World*, but for now GRW is beyond the scope of this present article.
5. I should note that even Heisenberg, who is cited by Russell for support, did not take this step, insisting that the atomic state is "not as real" as the things and facts determinable from experiments and in our daily lives (Heisenberg 1990, 173–74).
6. Of course, there are metaphysically realist interpretations of QM that go beyond the formalism in such a way—and GRW is the obvious one, as noted in my endnote iv—but any model of QDA based on these would need to grapple with difficult new ontological challenges.

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