DOES GOD CHEAT AT DICE? DIVINE ACTION AND QUANTUM POSSIBILITIES

by Nicholas T. Saunders

Abstract. The recent debates concerning divine action in the context of quantum mechanics are examined with particular reference to the work of William Pollard, Robert J. Russell, Thomas Tracy, Nancey Murphy, and Keith Ward. The concept of a quantum mechanical "event" is elucidated and shown to be at the center of this debate. An attempt is made to clarify the claims made by the protagonists of quantum mechanical divine action by considering the measurement process of quantum mechanics in detail. Four possibilities for divine influence on quantum mechanics are identified and the theological and scientific implications of each discussed. The conclusion reached is that quantum mechanics is not easily reconciled with the doctrine of divine action.

Keywords: determinism; divine action; hidden variable; indeterminism; measurement process; physics; projection postulate; providence; quantum event; quantum mechanics; Schrödinger's Cat; wavefunction collapse.

INTRODUCTION

About the year 1225, Landulph, Count of Aquino, and Theodora, Countess of Teano, gave birth to a son. Their child, Thomas Aquinas, grew to be one of the greatest intellects in the history of the church and someone who was intensely interested in both God and the nature of creation. While

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[*Zygon*, vol. 35, no. 3 (September 2000).]
 ISSN 0591-2385

few of us today would claim to have a better insight into God's universe than Aquinas, any one of us could thrill and inspire him by giving *our* description of the world he inhabited. The reason we are in this position is not because we are in any way better than Aquinas but simply by virtue of the date of our birth. This is the legacy that Copernicus, Newton, Darwin, and their fellow scientists have left us, and it means that we not only know more about the universe than Aquinas did but have a far better comprehension of its structure and construction.

It is undeniable that these developments have resulted in a vast change in the way that humankind perceives the world. The change, however, has been achieved at a considerable cost to what is often identified as "traditional" theology. The outstanding successes of the natural sciences over the past three hundred years have caused an intellectual shift that has challenged both biblical authority and the intellectual credibility of much received religious doctrine. Of all the challenges science has raised for theology, perhaps the most fundamental is that it has brought into question the doctrine of divine action.

It is central to Judaeo-Christian faith that God has acted in history and continues to act today. Christoph Schwöbel has demonstrated just how fundamental this concept of special divine action is: he names concepts such as thanksgiving, confessions of faith, and petitionary prayer and emphasizes their dependence on God's particular actions in creation (Schwöbel 1992, 23–24). Yet this concept of a God who acts in the world has become increasingly difficult to defend in the face of our modern scientific worldview. Indeed, the causally closed view of science in which every event leads to another seems to many to leave no room for God at all. As William Pollard put it in the introduction to a book that came to be identified as the forerunner of much of this whole debate: "I found extraordinary difficulty, when I thought about events in scientific terms, in imagining any kind of loophole through which God could influence them" (Pollard 1958, 12). Many of today's theologians would dislike Pollard's terminology, although they do in essence agree with this sentiment. For many, the causal nexus of science seems to draw so tight that the divine Providence that forms such a central part of biblical narratives is now often viewed skeptically or even dismissed entirely (Gilkey 1961). It is of primary importance, however, for Jewish and Christian theology to encompass divine action; if God is unable to act, then even petitionary prayer is useless: there is simply no way for God to "give us our daily bread" (Saunders 1999a, 36).

So, has belief in special divine action been irrevocably lost to science? Several modern theologians have argued against this irreducibly causal picture of science and answered a strong No to this question. They have done so by challenging the underlying deterministic interpretation of science, and some also argue that in these indeterminacies they have found a potential point of interaction between God and creation. Their argument is based largely on the development of quantum theory earlier this century. What makes quantum theory so radically different from classical physics is that it cannot be known in principle what an object described by quantum mechanics will do under every circumstance—the best we can do scientifically is to say that there is a set of possibilities open to it and that sometimes it selects one of these possibilities, but we can't tell which. So it seems that quantum mechanics is offering us a complete description of the object of study, and it is possible to predict scientifically in what proportion of cases a particular possibility will result, but only a proportion, because we know of no rule or law that in principle determines the result in any particular instance.

Consider an analogy first proposed by Bertrand Russell (1935, 154–55). Suppose you were a giant who could not see individual persons and never became aware of an aggregate of fewer than a million of them. You would be able to notice that London contains more people by day than by night, but it would be impossible for you to determine on a particular day whether Dr. Dixon was ill in bed and did not take his usual train. Thus, you would believe the movement of people in and out of London to be much more regular than it usually is. If later it became possible to observe individual persons, you would find that there is considerably less regularity than you had supposed. One day Dr. Dixon is ill, and another day, Dr. Watts. If the same number of people stay home each day, the statistical average is not affected, and in your large-scale observations there is no difference. The analogy to quantum mechanics is this: most experiments that physicists do using the principles of quantum theory only examine the processes of large ensembles of quantum entities. The claimed indeterminacy in quantum theory is primarily concerned with the behavior of individual quantum particles out of the many that form a composite system rather than the bulk behavior of the system as a whole.

It is precisely because of this purported ontological indeterminacy that a large number of scientifically interested theologians have recently considered the possibility of an influence on quantum mechanical events as one means by which the divine will may be expressed in creation. In doing this they form part of a tradition that started with the founding fathers of quantum mechanics themselves, who were often concerned with the philosophical and theological implications of their work. Soon after the development of quantum mechanics, Albert Einstein made the assertion that he could not conceive of a God that "played dice." What made him doubt the authenticity of quantum theory was the assertion that it was ultimately statistical in nature, and Einstein, who believed that all science was ultimately deterministic and causal, interpreted these statistics as evidence that there were significant problems with the theory. Later philosophers have shown, however, that Einstein might be wrong about this point. Quantum mechanics is a phenomenally successful theory, and one of the most common interpretations of it asserts that these indeterminacies are ontological in character. Many theologians have seized upon this and linked it to a theology of divine action. It is the aim of this paper to evaluate this work and consider the extent to which God can be said to "cheat at playing dice."

WHY LOOK FOR DIVINE ACTION IN SCIENCE?

Before we turn to consider the work of certain scholars in this field and the nature of quantum mechanics in more detail, we must first briefly address the question of why it is that quantum mechanics should be of any relevance to the doctrine of divine action. After all, Aquinas, with whom we began our discussion, did not need the indeterminacies of the atom for his theology of divine action. It is remarkable how rarely this point is considered, given that it lies at the foundation of all of this scholarship. Indeed, it also seems to be rarely appreciated that the change in theological outlook that has occurred since Aquinas's time is almost as radical as that which has occurred scientifically. The theory of knowledge that underpinned most theological scholarship in the Middle Ages was this: humanity was originally created with full knowledge of all natural things and with sufficient knowledge of God to satisfy all human needs. Following the Fall, a large proportion of this knowledge was darkened or blurred; nevertheless some of it still remained, and some of that which was lost could be recovered by subsequent biblical revelation. It thus followed that the main task of scholars in the Middle Ages was not to make new discoveries but to collect and restore the old knowledge by making it suitable for the present. As Sir Richard Southern has put it:

> The problem was not "How do we know?" for to know was inherent in man's nature. It was not even "How do we restore what was lost by the corruption of man's nature?" for this task had largely been already accomplished. The problem was, "How can we rediscover and make easily available the records of old knowledge and put the whole together in a usable form?" In this task, observation of physical phenomena could play only a small part. (Southern 1992, 152)

The questions theologians ask about creation have undergone a transformation, too. The rise of science as an explanatory principle not only has challenged biblical theology but moreover has led to an entirely different mode of questioning about theological issues. In part these discussions about the applicability of quantum mechanics to a theology of divine action are a product of this post-Enlightenment change in theological method. This fact seems to have been missed by many of the scholars in this field, and it is perhaps remarkable that "traditional" theology is cited so much in this context. Most traditional (or pre-Enlightenment) theologians would never have asked these questions at all.

There also is a need for clarification about the nature of "biblical" theology as a motivation for belief in special divine action. When examining the doctrine of God's providential care and maintenance of creation it is almost always Old Testament sources that are used. It is notable, however, that the theme of divine action in creation (as distinct from action through human beings) is only a very small element of the New Testament. We should not be surprised by this, given the emphasis of the New Testament on the works of the spirit in a human context.

Consequently, we should be careful about identifying the context for these debates. Indeed, why should God act *through* the mechanisms of science at all? At first glance there appears no reason why this should be so; one of our primary assertions is that God is all-powerful and as such not limited to acting in ways that are consonant with scientific laws. Yet most of the advocates of divine action through science consider God's power to be somehow limited by creation. Indeed the idea that God acts *through* science is underpinned by an influential doctrinal tradition dating principally from Aquinas, who asserted that God acts in the secondary causality of creation.[1] We can see this philosophically from the assertion that God acts in a logical manner. As Richard Swinburne has put it, "it must be held that God is a logically contingent being" (1979, 76). While God is not limited to the created order and remains transcendent, there are strong arguments for God's interaction through it. The ontological reality of nature that science attempts to express is a result of God's creation and as such an expression of God's will. God is free to act in whichever ways God chooses, but it is consistent for the divine will to act within the laws of nature it has previously established and continues to maintain. This sentiment is well expressed by John Polkinghorne, who writes that "the divine will is always self-consistent, and the last thing that the rational and faithful God can be is a capricious, celestial conjurer" (1996, 245).

Few of the authors discussed in this paper would assert that bottom-up action by means of quantum mechanics is the only place in God's creation that divine action can occur; however, William Pollard, Nancey Murphy, Robert J. Russell, George Ellis, Thomas Tracy, Keith Ward, Philip Clayton, and many others have propounded it as a realistic possibility. Why is this so? The basis of their arguments is that quantum mechanics expresses an ontological indeterminism that is a fundamental feature of nature. This indeterminism is not extended to God, who because of omniscience can see behind it and as such can control and manipulate it[2]—achieving thereby specific aims from within the causal nexus in a way that is perfectly consonant with scientific regularity. The proposal that God acts through quantum theory thus hinges on this indeterminism, which allows God enough "space" to act in creation.

Before we begin a discussion of the proposals various theologians have made for quantum mechanical divine action, we shall examine quantum mechanics in some detail.

THE SCALE OF QUANTUM EVENTS

It is remarkable that a theology of divine action should be linked to quantum-scale events. Almost all theological discussion of divine action concerns what scientists call "macroscopic events." By this they mean objects and phenomena on the scale of human experience, such as billiard balls, burning bushes, and the Red Sea. Quantum mechanical events, on the other hand, concern very, very small objects. In fact it is a challenge to describe quite how small things have to be for the indeterminacies of quantum mechanics to be prevalent. The length of a huge object in quantum mechanics (for example, a sodium ion) is on the order of 10^{-10} meters. To put this size in some perspective, imagine the difference in size between a pinhead and planet Earth. If we could shrink them both until the Earth were the size of a beach ball, the pinhead would now be the size of a large quantum object. At first sight, then, it seems truly amazing that burning bushes should be related to events on this scale. What rescues us from this is the fact that quantum interactions are incredibly common.

It is difficult to appreciate quite how fundamental quantum mechanics is. Bernard Levin, writing in the *London Times*, demonstrated how ignorant he was of this fact:

> Despite their access to copious research funds, today's scientists have yet to prove that a quark[3] is worth a bag of beans. The quarks are coming! The quarks are coming! Run for your lives . . . ! Yes, I know I shouldn't jeer at science, noble science, which, after all, gave us mobile telephones, collapsible umbrellas and multi-striped toothpaste, but science really does ask for it. . . . Now I must be serious. Can you eat quarks? Can you spread them on your bed when the cold weather comes?

It didn't really need a reply, but Cambridge scientist Sir Alan Cottrell wrote a brief letter to the editor: "Sir: Mr. Bernard Levin asks 'Can you eat quarks?' I estimate that he eats 500,000,000,000,000,000,000 quarks a day."[4]

Their minute size and the frequency of quantum events means that we can experience the consequences of fundamental quantum phenomena in our macroscopic world but do not have any direct experience of the phenomena themselves. A fundamental difference between quantum mechanics and classical physics is that quantum theory allows the possibility of an object being in two different states at the same time (this is called the *superposition principle*). This point was vividly made in the famous Schrödinger cat paradox, in which the unfortunate feline is left suspended in a mix of being both dead and alive (Schrödinger 1980). However, none of us has ever *seen* cats, billiard balls, or buses as "fuzzy" superimposed or unresolved objects.[5] There are two reasons for this: first, the act of measurement is extremely important in quantum theory, as we shall see; and second, there exists some mechanism whereby the indeterminacies of quantum processes are resolved on our macroscopic level. Indeed, the precise nature of the relationship between quantum-scale phenomena and the macroscopic world is still a matter of considerable debate in quantum theory. This has led some, notably Polkinghorne, to criticize the application of quantum mechanics to theology. While his fears are well justified, it seems that it would be profitable to consider more precisely the implications of the general thesis that God acts in quantum theory. Quantum mechanics is a precise science, not a realm of fuzziness, and as such it is necessary to consider the specific implications of the proposals made by the advocates of quantum mechanical divine action. Simply saying that God influences quantum mechanics is not enough—we must further consider how this action could be consistent with our current understanding of the theory. It is not satisfactory to simply point to quantum mechanics and make broad sweeping conjectures about special divine action. The onus is upon theologians to look at quantum mechanics in all its technical detail in order to substantiate their claims; only then could the possibility of quantum divine action be credible. Yet, as we shall see, the implications of the various alternatives quantum theory offers are not as simple as many theologians have assumed.

The Role of Determinism

We begin our study of the potential relationship between quantum theory and divine action with the element of the theory that makes it most attractive to theologians: it is commonly held to be fundamentally indeterminate in nature. It is widely believed that Newtonian physics is deterministic and that quantum physics is indeterministic; however, as we shall see, this is a gross simplification. Indeed, there remains a fundamental sense in which the concept of determinism may remain elusive no matter how much we study a particular physical theory in relation to another. The reason for this is that the notion of determinism is itself somewhat circular—"we cannot begin to discuss the implications of physics for the truth of the doctrine of determinism until we know what determinism is; on the other hand, no precise definition can be fashioned without making substantive assumptions about the nature of physical reality" (Earman 1986, 4). The problem is that the nature of these assumptions varies as we move from Newtonian to general relativistic to quantum physics, and our definition of determinism must move similarly. To circumvent this difficulty as far as possible, let us consider a possible notion of determinism proposed by William James in an address to the Harvard Divinity School students of 1884:

> It [determinism] professes that those parts of the universe already laid down absolutely appoint and decree what the other parts shall be. The future has no ambiguous possibilities hidden in its womb: the part we call the present is compatible with only one totality. Any other future complement than the one fixed from eternity is impossible. The whole is in each and every part, and welds it with the rest into an absolute unity, an iron block, in which there can be no equivocation or shadow of turning. (James 1979, 117–18)

I propose to take this as the most theologically useful definition of determinism. James's vision of the "iron block" of a fixed deterministic future accords well with the many comments scientist theologians have made in this regard. Moreover John Earman (1986) has persuasively shown how difficult it is to refine further upon James's discussion. So let us for a moment consider a totally deterministic world in which the causal nexus of science is drawn so tight that there is no real freedom for either God or human beings. In such a world Laplace's famous demon reigns supreme. God cannot act in any creative way through the causality of science and still remain true to the deterministic rules put in place at creation. In such a system God is also totally responsible for all evil in the world. Given this implication it is hardly surprising that theologians are keen to consider the possibilities of modern physics that express an indeterminacy in nature such that God can act while remaining true to the creation.

How Deterministic is Quantum Mechanics?

According to Niels Bohr, quantum theory must not be interpreted as a description of the nature of the world but merely as a tool for making predictive observations: "in our description of nature the purpose is not to disclose the real essence of the phenomena, but only to track down, so far as is possible, relations between the manifold aspects of our experience" (Bohr 1934, 18). Bohr appears strongly instrumentalist in his approach to quantum theory; in fact, he held that epistemological analysis of quantum phenomena had a metaphysical priority over what he considered to be misguided ontological conjecture. Bohr's approach thus forbids any detailed realistic claims being made about quantum theory—he considered quantum phenomena to be completely sealed behind an impenetrable shield of classical concepts and complementarity.

Bohr's overly pessimistic assessment of quantum theory is shared by few of today's philosophers of science. Given, then, that it is widely accepted that it is possible for us to make ontological claims based on quantum mechanics, it becomes possible to ask how close to James's conception of determinism quantum theory lies.

Whether we agree with Bohr's convictions or not, it may seem plausible that a possible argument for determinism is based on our present ignorance about quantum mechanics, which may be refuted tomorrow by a new discovery. Such discussions of the completeness or incompleteness of quantum theory have been common in the past. Now, however, it is commonly agreed that the existing quantum theory is a complete model. For the purposes of this discussion we shall therefore accept it to be complete and self-consistent.[6] With this assumption, then, the key point is that current quantum mechanics is both *extremely deterministic* and *potentially indeterminate*.

Ernest Nagel has noted that "an examination of the fundamental equations of quantum mechanics shows that the theory employs a definition of state quite unlike that of classical mechanics, but that relative to its own form of state description quantum theory is deterministic in the same sense that classical mechanics is deterministic" (Nagel 1982, 306). This is a technical statement that deserves some explanation. Nagel is emphasizing here that the structure of quantum mechanics is constructed in a deterministic way exactly analogous to classical mechanics. This important fact is not widely appreciated. As Nagel himself emphasizes, given a quantum system at some particular time, the Schrödinger equation determines a unique possible set of values for that system at all subsequent times. So it seems from this that quantum mechanics accords well with James's vision of the future having no ambiguous possibilities whatsoever. Accordingly we can say that there is *no indeterminacy in the way that a system described by quantum mechanics changes with time if it is left on its own.* Indeed Earman has extended Nagel's claim to argue that the evolution with time of a quantum mechanical state is in many ways *more* deterministic than classical mechanics (Earman 1986, 200).

The wave (or state) function is a mathematical expression that represents whatever quantum objects we are studying. It has one form for an electron in a certain state, another for a sodium ion, another for Schrödinger's Cat, and so on. The evolution with time of the state function is fully determined by the Schrödinger equation. Earman argues that the famous Schrödinger equation of quantum theory is not only every bit as deterministic as classical mechanics but even more so. The technical reason for this is that the Schrödinger time evolution equation preserves the "norm of states," which implies stability in the past and future, in contrast with classical mechanics, in which highly sensitive dependence on initial values can result in imprecise prediction (the basis of chaos theory). It is very important to note at this point that the determinism of the time evolution of a quantum state governed by the Schrödinger equation is not dependent on which interpretation of the philosophy of quantum mechanics we accept. It is a totally basic feature of the theory.

So why is it that quantum mechanics is held to be indeterminate and thus attractive to theologians? The point where indeterminacy is commonly held to enter quantum theory is at the point of *measurement.* We can easily see this by recalling the Schrödinger cat paradox—it is only when we open the "lid" of the box that the cat resolves into either a dead or an alive state. There are thus two fundamentally different processes governing a quantum system: the steady deterministic evolution of the wavefunction governed by the Schrödinger equation, and the fitful, potentially indeterministic processes that occur when the system is measured.

The difficulties occur when we try to consider what actually happens in this scenario. To put the question another way, What actually is a quantum mechanical "event"? If we consider it to be the observation by a human observer, then we know how to judge that the event conforms with our preconceptions. If, however, we consider the event to be something in the external physical world itself, then we need some sort of mathematical description of what is happening. The deterministic evolution under the Schrödinger equation is such that *no particular event ever happens*. Instead, what we have is a gradual, smooth development according to a simple rule. Nothing remarkable happens—Schrödinger's cat remains in a mix of dead and alive states indefinitely. So it is reasonable to say that if one considers only the wavefunction and the Schrödinger equation determining quantum mechanics, one finds that the "event" never really takes place. This is of vital importance to the theological debate and is misunderstood by some of the scholars in this field.

This is not quite the whole story, however. Let us be more precise. In actual fact, *every possible event occurs at the same time*, and there is no singling out of the one event from this superposition of possibilities. The technical reason for this is that the wavefunction can be what is called a superposition of states—recall Schrödinger's cat being both dead and alive at the same time. The fact that from the viewpoint of quantum mechanics Schrödinger's cat is *really* both dead and alive is highly counterintuitive. Yet it is a situation that arises quite naturally from the superposition principle and the fact that the wavefunction has the mathematical properties appropriate to a representation of probabilities only.[7] Despite this, we can perform measurements on quantum systems and obtain real values for certain quantum objects. The implication of this is that there must be some type of disruption to the superimposed state in which every quantum possibility exists simultaneously. As we noted earlier, buses do not appear in a superimposed state of turning both right and left at the junction between two roads. Measurement in quantum mechanics is thus a very strange thing, and it has an ontological status entirely different from that in classical mechanics.

To help describe the processes that determine whether Schrödinger's cat is dead or alive, we thus have several different mathematical options (Stapp 1987, 258–59). We know for certain that when we measure it is in either one of the two possible states, so what we need is a theory that decides which of these two it becomes. There are a number of different ways that this could be done (these are often called "solutions" to the measurement problem); we shall consider three of the most common here.

The first option is that we could introduce objectlike entities into our deterministic theory to represent actual things. This was the approach taken by Louis de Broglie and David Bohm and leads to their so-called pilot wave, which works in tandem with the standard mathematical description given by Schrödinger to single out one possibility at the act of measurement and decide the fate of the unfortunate cat (Bohm and Hiley

1993). Although this alternative formulation of quantum mechanics is very successful, it has been criticized on the grounds that it is an arbitrary assertion that does not represent reality. There are also some major technical difficulties with Bohmian mechanics that need to be resolved before it becomes widely accepted.

For our purposes the de Broglie-Bohm reformulation of quantum theory is particularly interesting, because it is a *totally* deterministic theory. In short, any problems we might have as scientists predicting the result of particular quantum experiments are explicable merely on the basis of a lack of our full knowledge of the workings of the system in question, rather than representing any fundamental indeterminism in nature. Given this, it is not surprising that none of the proponents of quantum mechanical special divine action adopts the de Broglie-Bohm approach. It is vitally important to note, however, that the formalism of quantum theory does not *demand* an indeterministic interpretation of quantum measurement processes.

A second way to mathematically single out one state at the act of measurement (or decide the fate of the cat) is to introduce idealike entities into the theory. These have the role of filling up all of the possibilities that exist in the superposed wavefunction. This is the so-called many-worlds interpretation of measurement and was first proposed by Hugh Everett III (1957). The basis of Everett's approach was the assumption that the evolution of the quantum system under the Schrödinger equation was totally pervasive and not interrupted by measurement processes. Accordingly this approach asserts that whenever a measurement is made, the universe branches out into as many varied versions as there are possible results to that measurement. At the end of the experiment there exists one universe in which Schrödinger's cat is alive and one in which it is dead.

This theory has received fairly widespread support despite its rather uneconomical nature and the fact that the many billions of parallel worlds that are thus formed must all be objectively real. Again it is vital to note that it is, like the approach of de Broglie and Bohm, a fully deterministic theory when viewed from the perspective of the full collection of universes. While this world may *appear* to be indeterministic to us (as we are unaware of the other worlds coexisting with our own), there is no point in the theory in which any form of indeterminism is introduced. Moreover, it seems unlikely that it would be fruitful for this approach to be linked to providence for other reasons (every providential act of God in one world forces other worlds into nonprovidential situations). God is thus obliged to choose one world in which to act providentially while the others are allowed to perish in anonymity. Such a view is far from the conception of God as a rational and faithful upholder of all the cosmos.

A third option is one that the majority of philosophers of physics find most acceptable: we introduce action-type entities to "collapse," or eliminate, the unrealized branches of the wavefunction. This forms an essential part of what is commonly known as *orthodox* quantum theory and owes its origins to John von Neumann (1955).[8] He asserted that at the act of measurement the wavefunction, or mathematical description, of the quantum system collapses into only one of the possible outcomes that formed part of the initial superposition. If we return to Schrödinger's cat, the mathematical description of the cat maintains the dual dead-and-alive nature up until the point of measurement, at which it is collapsed from these two possibilities into only one. If the cat is measured as being alive, then the branch of the wavefunction corresponding to the dead cat simply vanishes, and vice versa. The main problem with this orthodox interpretation is that there is no way for us to determine which of the multitude of possibilities will be selected, and it is precisely this fact that has stimulated all of the assertions that quantum theory is fundamentally indeterministic and accordingly that it may contain enough flexibility to incorporate God's purposive actions.

We are now in a position to answer the question we posed above, namely, What is an *event* in quantum mechanics? As we have seen, the answer to this question can only be something that distinguishes between the different possibilities inherent in the superpositioned wavefunction and results in one particular possibility being selected. Returning yet again to Schrödinger's cat, an event occurs at the time that the cat is selected as being either dead or alive. If we exclude many-minds and many-worlds interpretations, this is the so-called wavefunction collapse, or, to use its technical name, the *projection postulate*.

Justification of the Projection Postulate

It may be helpful to summarize in advance the discussion that follows in this section. Quantum theory is a fundamentally deterministic theory, which can be interpreted, according to the orthodox response to the measurement problem, as containing an indeterministic element. No quantum events occur *until the act of measurement* by some process separate from the system in question. On measurement, the wavefunction is most commonly held to collapse from its multibranched nature of many possibilities into one particular state. The selection of this state happens in an indeterministic manner from the possibilities inherent in the wavefunction, or mathematical description, of the system in question. It is important to note that the following discussion does not focus on the plausibility of hidden-variable theories or any specific interpretation of the measurement problem other than accepting the projection postulate. The critique I offer in the final section is also intended to be as free as possible from these interpretational issues.

If we accept the indeterminism of quantum measurement, then there is still the problem of justifying the projection postulate or wavefunction collapse. At first sight it appears a fairly arbitrary assumption on the part of the physicist and not necessary to the formulation of quantum mechanics. The importance of the de Broglie-Bohm pilot-wave theory discussed earlier lies primarily in showing that it is possible to construct a theory of quantum mechanics that does not rely on the same assertions as the orthodox theory and yet still fits the experimental data. Indeed there is at first sight no reason why a normal Schrödinger evolution of the composite system of both measuring device and system under measurement should induce an event on one of its components of the kind described by the projection postulate.

Nevertheless, the projection postulate does have some experimental basis. The implication of the postulate is that if a measurement is repeated immediately it should give the same result as the first, and this is found in practice to be at least approximately true. If we reconsider Schrödinger's cat, we can see how this should be the case: we open the lid of the box and determine whether the cat is dead or alive; if soon after this we check again, we do not expect to find a different result (unless the poor cat also has a cardiac condition and dies of natural causes!), because the state of the cat is then fully determined under the Schrödinger equation's normal time evolution, as we have seen. Nevertheless, despite the fact that there is this strong experimental support for a collapse mechanism at the point of measurement, it is not possible to justify the projection postulate a priori.

Given the above considerations, it seems reasonable to accept the projection postulate as being a standard feature of quantum mechanics and as having an ontological basis. However, as we have seen, it is possible to formulate two other types of quantum theory, neither of which entails the collapse of the wavefunction upon an event. While most practicing scientists would wholeheartedly support the thesis of wavefunction collapse, it is crucial to note that it is not *in principle* a necessary feature of quantum mechanics. All of the proponents of divine action in quantum mechanics that we are considering support wavefunction collapse implicitly. They are certainly not outside scientific orthodoxy in doing this; but they limit their discussion to this interpretation of quantum theory. For the purposes of engaging with their work in what follows, we too shall restrict the remainder of the discussion to orthodox quantum theory with the projection postulate.

It is important to be clear about the status of determinism in quantum theory. Essentially, orthodox quantum mechanics consists of two fundamentally different processes: deterministic evolution under the Schrödinger equation and indeterministic collapse at the point of measurement. The concept of an "event" in quantum mechanics can be applicable only to this second, measurement, process. If God acts consistently with the principles of quantum mechanics by exploiting the indeterminism of the orthodox interpretation, then these actions can take place only by some type of measurement interaction. The Heisenberg Uncertainty Principle does not provide the flexibility required to diminish James's vision of a deterministic universe (Saunders 1999b, 208–14).

Discussion of the Protagonists of Quantum Divine Action

The thesis that God acts through quantum mechanics is possibly one of the most commonly held interpretations of divine action. Many scholars in this field have written excellent work on this subject. Moreover, it is a thesis that has been very well received by the theological community at large. Brian Hebblethwaite echoes the thoughts of many theologians with his assertion that an argument for divine action through indeterminism is "entirely convincing" (Hebblethwaite 1990, 100). We shall see that there are major similarities between these authors' conceptions of divine action, although they differ as to the extent of the divine influence on quantum processes and the precise method of interaction.

William Pollard. The origins of much of this scholarship are to be found in the work of William Pollard, an Episcopalian priest, former physicist on the Manhattan nuclear bomb project, and professor at the University of Tennessee. Pollard was primarily concerned with reconciling what he saw as the intolerable differences between the scientific and biblical accounts of nature. His methodology has become somewhat paradigmatic: first, Pollard identifies the tension between the biblical interpretation of providence and deterministic science; second, he discusses the indeterminacies of quantum theory and thus concludes that most of science is ontologically indeterminate; and third, he links the providential action of God to these indeterminate processes.

Pollard categorically rejects any interventionistic account of divine action as being contrary to the biblical interpretation of creation and argues that it "inevitably places God and nature in opposition to each other in the sense that they represent two alternative causative agents" (Pollard 1958, 26). He also rejects an interventionistic account of divine action on purely scientific grounds:

> It is like seeing a great actor stop in the midst of a magnificent performance to pick up a line from a prompter, or a master craftsman tampering awkwardly with an otherwise perfect creation. Anyone who has had the privilege of having the whole marvelous structure of mathematical physics unfolded before his imagination and experienced the thrill of it cannot fail but find the thought of such intervention shocking. (Pollard 1958, 28–29)

Pollard makes an implicit assumption about the nature of scientific explanation common to many of the authors in this field—he argues that any event that occurs in creation should *in principle* be explicable from an entirely scientific viewpoint. This is a strong assertion about the nature of scientific explanation, rendered all the more remarkable by Pollard's later conclusion that God is active in every quantum event as the "object and exercise of the divine will" (1958, 114). Indeed, Pollard avoids the charge of interventionism by even considering miracles to be events that remain entirely within the natural processes of nature: "Biblical miracles are, like that in the exodus, the result of an extraordinary and extremely improbable combination of chance and accident. They do not, on close analysis, involve, as is so frequently supposed, a violation of the laws of nature" (1958, 115).[9]

These arguments place strong limitations upon God, and ones that it would be difficult to find in Pollard's original biblical motivation given its emphasis on divine freedom. It is within this context that Pollard formulates his connection between divine action and quantum indeterminacies. Although he is not as explicit about the role of quantum indeterminacies as many who have followed him are, Pollard is still fairly strong in his assertion. He is against any conception of God modifying probabilities of a particular event to occur. Doing so, he argues, would entail that God is simply a cause in the world acting in a way similar to other causes. Moreover, such a conception of altered probabilities is totally nonbiblical: "Providence is made manifest in single events, not in multiple tries to which probabilities can be assigned" (1958, 96). Nevertheless, every quantum event has a divine input because it is the result of both the operation of universal natural law and the exercise of divine will.[10]

Given that Pollard's thesis entails the determination of every quantum event by God in conjunction with the operation of universal natural laws, it is difficult to understand in what sense these laws could be universal if this is the case. God must be involved in a fairly unfaithful and irrational maintenance of the probabilities that form a fundamental part of quantum mechanics if God acts in every quantum event. In what sense are they really probabilities if this is the case? Indeed, Pollard's conception of providence seems really to be a species of occasionalism—something he was keen to avoid. He is consequently also prone to a particularly strong problem with the role of evil in the world, especially given his assertion that all human history is the work of God and not that of human beings.

There is another, perhaps more fundamental, difficulty with this position. It is essential to Pollard's theology of divine action that the universe is ontologically indeterminate in its nature, to give God "space" (as he calls it) to act. He then argues that the new physics of quantum mechanics introduces indeterminism into science and that these indeterministic processes are of a nature that is consonant with divine providence. He also asserts, however, that God acts to determine every indeterministic quantum event and that all acts of God occur within the matrix of scientific explanation. In a sense, then, he moves full circle and eventually provides a theology of divine action that is related to a deterministic worldview—a science determined by God.

Nancey Murphy. Another important author in these debates is Nancey Murphy, who maintains a position similar to Pollard's in asserting that God is active in all quantum events. Murphy's approach results principally from theological considerations concerning the various criteria a satisfactory theory of divine action must meet. Accordingly, if, as she argues, God is active in all aspects of creation, then it is a logical conclusion that God is acting in quantum events. She differs from Pollard in that she restricts all divine action in nature to an exploitation of quantum mechanics, while Pollard connects God with pervasive indeterminisms operating at all levels of complexity within creation. In this context she offers what is possibly the most detailed description of a mechanism of divine action.

Murphy proposes a scheme whereby God is involved in determining the outcome of quantum events, and she reaches the conclusion that God has a controlling hand in each and every quantum event. The basis of Murphy's proposal is that God does not alter the fundamental behavior of quantum entities but simply chooses different behaviors at different times. Accordingly, God's action is limited in two respects: "God's governance at the quantum level consists in activating or actualizing one or other of the quantum entity's innate powers at particular instants" (Murphy 1995, 342), and divine action is restricted so that it produces a world that is orderly and lawlike in operation. As I understand it, Murphy envisages quantum particles having an innate palette of possible behaviors, and God selects which of these behaviors are expressed by the particles at any particular instant. It is, however, difficult to understand precisely what these innate powers actually are in scientific terms if God maintains and determines them entirely. The "natural rights" (Murphy's term) in question must be a product of divine regularity, and yet this divine regularity itself must incorporate any actions God might be making in creation. Moreover, as we shall see, it is unclear whether quantum mechanics really supports the distinction Murphy wants to make between God triggering the action of an entity and God performing the action, when God is held to have control over every quantum event. While Murphy's approach is potentially a strong one, it really requires a supporting philosophical interpretation of quantum theory that enables her to claim that "the apparently random events at the quantum level all involve (but are not exhausted by) specific, intentional acts of God" (Murphy 1995, 339).

One issue that makes this interpretation less than straightforward is the difficulty surrounding the term *events* in quantum mechanics. Polkinghorne has argued that a theology of divine action consonant with quantum mechanics results in a theologically unacceptably episodic doctrine of divine action. The reason for this criticism is the fact that measurements in his view are relatively infrequent events in the world. Murphy rebuffs this argument by citing Robert Russell's playful claim about the "innumerable quantum events" that go to making Schrödinger's cat (Murphy 1995, 356–57). The issue here is, as we have already seen, the question of what events are suitable for quantum divine action. We have argued that only where indeterminism is introduced to the theory can divine action take place and that, accordingly, measurements are the only suitable loci for divine action. Under this reading there are no events in quantum mechanics that satisfy Murphy's requirements for this thesis other than the orthodox interpretation of quantum mechanics with its associated wavefunction collapse. The time evolution of a quantum mechanical system (such as Schrödinger's cat) is governed by the Schrödinger equation, which is, as we have seen, even more deterministic than classical mechanics. Indeed, the whole point of the cat paradox is the distinction between the evolution of a system and the act of measurement. It is the fact that these measurements need not happen at frequent regular intervals that leads to Polkinghorne's criticism. In effect, God can act in creation only when someone or something opens the lid and measures the cat.

Despite these technical issues, Murphy's approach does have a self-coherence that is almost unique among advocates of quantum divine action. One may disagree with her starting point, but this bold systematic attempt to develop a coherent theology of divine action is to be applauded as a major contribution to the field.

Thomas Tracy. Tracy adopts a position similar to Murphy's but different in two fundamental ways. First, Tracy makes the assertion that God influences only *some* quantum events, not every one. Second, he does not limit God's action in nature to quantum manipulations. He differs in his motivation for linking divine action to the processes of quantum mechanics and emphasizes how different his objectives are from a "God of the gaps" theology. There is still a possibility that any gaps in which we choose to use God as an explanatory principle will be closed by a future scientific advance. What Tracy does see as theologically acceptable, however, is the linking of doctrine to what he terms "explanatory gaps in principle" (Tracy 1995, 291).

Tracy is strong in his assertions and argues, in a way similar to Keith Ward below, that the existence of these "explanatory gaps" is a *theological* prerequisite for a meaningful doctrine of divine action: "if we wish to affirm not only that God enacts history . . . but also that God acts in history, then there are good reasons to think that the world God has made will have an open ('gappy') structure" (Tracy 1995, 310). Tracy argues that both indeterministic chance and free agency are possible examples of causal gaps that might be of importance in this context. Because the causal gaps that form an integral part of quantum theory are describable by the laws of statistics when many of them are considered together, they also satisfy his criterion that any suitable gap must be part of the order of nature and not an arbitrary event within it. Tracy is perhaps the most perceptive of the scholars considered here when it comes to the problems associated with linking theology to quantum mechanics, and there is much in his sensitive account to commend it: he visualizes God realizing "one of the several potentials in the quantum system (the 'wave packet'), which is defined as a probability distribution" (1995, 318). God is not active in every quantum event and acts in those that have macroscopic consequences while remaining true to the bulk probabilities predicted by the theory. As he puts it, "God is the God of the gaps as well as the God of the causal connection" (1995, 320).

Keith Ward. Ward has much in common with Tracy in his theological assertion that the universe must necessarily have explanatory gaps in its structure. He makes what is arguably the strongest assertion in any of this literature about the gappiness of creation. Indeterminism, Ward argues, is so fundamental to any doctrine of divine action that he cannot conceive of God working in any meaningful sense without it: "if God acts (brings changes about intentionally) there are states of the physical universe which are not sufficiently explained by the operation of physical causes alone. To put it in the words of the crude formulation, there must be gaps in physical causality, if God is ever to do anything" (Ward 1990, 77). It is interesting to note the basis of his claim—Ward holds God's self-coherence as the primary feature of his theology and accordingly argues that divine freedom to act in creation is entirely limited by this, so that there must be "gaps" to give God sufficient "space" for action.

Seeing that he advocates indeterminism as fundamental to the doctrine of divine action, it is not surprising that he makes claims about quantum mechanics. He writes that "if the openness is really present, and is part of the structure of scientific law, then God would not be 'violating' the laws of nature if he did determine particular [indeterminate] events within the limits allowed by the structure; nor would such action be detectable by scientific methods" (1990, 79). This is a perfectly correct statement, but as we have seen from our discussion Ward's "events" are what we identify as quantum measurements in scientific terms. This is of vital importance, as we shall see.

Robert J. Russell. Russell has probably published more supporting the claims of quantum mechanical divine action than has any other author. Indeed, he recently extended this work by developing a thesis in which God is responsible for controlling genetic mutation and thus the processes of evolution by means of determining quantum events. This is in many ways a perfectly logical continuation of the main idea that God providentially determines some quantum events. In one of his most recent papers (Russell 1997) he describes this conception of quantum divine action in some detail.

In common with many scholars making similar claims, Russell uses quantum divine action to try to formulate a theology whereby God can act objectively in special events without intervening or suspending the laws of nature. In this context he has formulated a "noninterventionist objective special divine action" (1997, 51). Quantum mechanics, Russell argues, provides an ontological indeterminism that fits well with a concept of bottom-up causality in this context. Russell suggests that we can view God as acting, "in general, at the level of quantum physics, to create the general characteristics and properties of the classical world, and . . . in particular quantum events, to produce indirectly a specific event at the macroscopic level, one we call an event of special providence" (1997, 58). Thus, following the classical distinction between necessary and sufficient causes, Russell asserts that nature provides the necessary cause but that God's action is what constitutes the sufficient cause of any particular event. There are some similarities here with Murphy's redefinition of *cause* as discussed above. Consequently, as Russell puts it, "metaphorically, one could say that what we normally take as 'nature' is in reality the activity of 'God + nature.' Alternatively, from this perspective, we really do not know what the world would be like *without* God's action" (1997, 58). God acts together with nature to bring about all events at the quantum level, and these events give rise to the classical world of our existence. Some events, however, have greater macroscopic implications than others. Russell consequently also makes a radical redefinition of causality in the world.

Summary. I have briefly considered the work of only a few of the scholars who support quantum divine action. I cannot hope in this space to present a discussion of their arguments that represents the many different nuances of their positions fully; I have attempted that elsewhere (Saunders 1999b, chap. 3). All of these proposals have an implicit assumption that God is able to foresee the consequences of quantum manipulations and to control and determine otherwise indeterminate quantum measurements. Accordingly all of these scholars strongly support the ontologically indeterministic orthodox interpretation of quantum mechanics and assert that this indeterminism can be controlled by God in order to achieve specific aims within creation in a noninterventionist manner. While they vary as to whether or not quantum mechanics is the only locus of divine action, of most interest to us here are their differences as to the extent of divine control of quantum mechanics (whether God is active in all quantum events or only some key events) and the nature of the control (whether God controls probabilities for a particular event to occur or precisely defines the outcome of some particular event).

It should be a matter of some interest to mainstream philosophers of science that the proposal that God acts in *every* quantum event is another potential candidate for a solution to the quantum measurement problem.

It is certainly less bizarre than the prospect of there being billions of universes existing simultaneously and dividing on each measurement occasion and should rightly take its place in mainstream discussions of quantum measurement. It is rejected here because of its unacceptable theological consequences.

While I am critical of these authors' conclusions, I do admire their pioneering scholarship in this complex field. What we now urgently need to do is attempt to develop this work by trying to determine more specifically the implications of the general thesis that God acts through quantum mechanical phenomena. If we propose that God influences quantum mechanics, we are compelled to examine precisely *how*. As we have seen, while it is not unreasonable to assert that quantum mechanics is ontologically indeterminate, this indeterminism functions in very specific ways.

Four Possibilities for Quantum Mechanical Divine Action

Some of the consequences of quantum theory, such as Einstein-Podolsky-Rosen correlations (Einstein, Podolsky, and Rosen 1935) and Bell's theorem (Bell 1964), entail causal anomalies on a quantum level (if many-worlds interpretations are excluded). However, these do not form suitable breaks in determinism for divine action. The reason for this is that it has been shown for various technical reasons to be impossible for these anomalies to be manifested in the macroscopic world if the theory of quantum mechanics holds exactly (Eberhard 1978). Given this, when looking for the possibility of divine action in quantum mechanics, we cannot cite any nonlocality relationships and must therefore consider only local effects on a system. If we were faced with the question of identifying all of the possibilities for divine interaction with quantum mechanics, there are four broad ways in which this could occur consonant with orthodox quantum mechanics as considered above.

1. God Alters the Wavefunction between Measurements. In this proposal, God alters the expression of the wavefunction, or mathematical description, of the quantum system in question so that it changes not only to represent the previous system but also to include as a superposition a new state that God wishes to become a possible outcome of a measurement. Let us reconsider Schrödinger's cat. On a very basic interpretation of the problem, the quantum superposition prior to opening the lid of the box can be considered as {alive + dead}. Now let us suppose that God wishes to add through divine action a third element to the superposition. The superposition then becomes {alive + dead + desired}, in which {desired} is the state God wishes to realize.

Although this alteration may at first sight seem reasonably consonant with science, it is not long before we run into serious problems both scientifically and philosophically. First, if we consider the wavefunction to be representative of reality, then by creation of a new component of the wavefunction {desired}, God is introducing into creation an entirely new component. This is a highly interventionistic action, hardly in keeping with the laws of science God created and maintains. It also is important to note that there are strong technical constraints on what the state {desired} can be—it must still be an eigenstate of whichever observable God wishes subsequently to measure.

Second, even if this state were introduced into the wavefunction, there would still be no divine determination for the next particular "event." At the point of measurement, there would be no guarantee that we would obtain the result God intended (and the more elements God adds to the superposition, the less likely each of them is to be selected at measurement). Because we normally consider divine action in the context of macroscopic phenomena, it is difficult to see exactly how this element of indeterminism can be allowed to remain. It would be necessary for God to "switch off" indeterminacy to be able to determine the desired result. This proposal has complicated implications for the theory of quantum mechanics, unless God is involving us in some kind of double bluff. The deterministic time evolution predicted by the Schrödinger equation simply does not permit the sudden introduction of a component into the wavefunction unless we additionally propose that quantum jumps occur outside measurement. In order to incorporate this into quantum mechanics we must introduce another nonlinear operation similar to wavefunction collapse. There is little justification for this step, and for this reason we must consider this option as unsatisfactory within the current understanding of quantum phenomena.

2. God Makes God's Own Measurements on a Given System. Given the deterministic nature of the evolution of the quantum state between measurements, it is conceivable that God could make measurements on a quantum system in order to determine outcomes. If we reconsider the example of Schrödinger's cat, what we are examining is whether it would be possible for God to have already measured the state of the cat and thus resolved it into the state of either dead or alive prior to *our* opening of the box lid.

As with the first possibility, this proposal seems initially plausible but soon causes difficulties for the simple reason that it does not seem to agree with our experiments. When we make measurements on a given system, we get results with a statistical distribution consonant with the probabilities that correspond normally to the superposition state that we posit exists prior to the new measurement. There have been no intermediate wavefunction collapses. Moreover, because all measurements in quantum mechanics involve interaction between parts of God's creation (it is necessary for something in the universe to perform the measurement), it is difficult to reconcile this proposal with standard quantum theory unless God fundamentally interacts via "tentacles" in creation which are in principle fully observable. Finally, it is difficult from a theological viewpoint to understand how God may achieve any directed purpose by this method. After all, and like the first proposal, it is not possible for God to actually specify a particular result. God can decide precisely at what time to "toss the dice" and produce an outcome, but this does not determine the result of a measurement. Given these considerations, this proposal is also highly unsatisfactory.

3. God Alters the Probability of Obtaining a Particular Result. When a quantum mechanical measurement is made, the possible results are closely related to the wavefunction. More technically, there is a certain probability that each of these results will be achieved that is related to the square of the modulus of the wavefunction. One possibility, then, is that God alters the probabilities behind a measurement so that the desired outcome is more likely. Indeed, given this possibility, there is no reason why God should not influence the probabilities such that they are of a trivial nature (that is, 1, or absolute certainty) to ensure the desired outcome.

This option is potentially consonant with divine action and as such justifies further examination. It does, however, rely on a particular philosophical conception of the nature of quantum mechanical probabilities. In essence, for this proposal to be true, we must assert that the probabilities exist as a propensity in nature prior to results being obtained.[11] This is not an unorthodox opinion, but the probabilities must *precede* the results and as such describe the nature of physical reality in some way. There is no reason why this should be problematic, although we must question the meaning of these probabilities if God frequently alters them. In short, we are forced into accepting Tracy's proposal of intermittent divine action in quantum mechanics over Pollard's and Murphy's notion of God as active in every quantum measurement. Moreover, because the probabilities of a particular outcome are so closely related to the wavefunction, it is not unreasonable to claim that in shifting these probabilities God is also altering the nature of reality *prior* to a measurement.[12]

This conception of altered probabilities in relation to measurement has been studied by Henry Stapp in his work on Weinberg's nonlinear generalization of quantum mechanics (Stapp 1994). Stapp at the time was working on purported empirical violations of orthodox quantum mechanics reported by parapsychological researchers. While staying clear of the question of whether the parapsychological research was valid, Stapp did manage to develop a model using Weinberg's work that accommodated a certain amount of probability shifting. It is easy to extend his work to model divine action via the same methods, but there are problems concerning the relationship of God to the created world. Stapp relies on a localized agent wishing the shift in probabilities; however, God is not localized in the same manner.

In summary, the question of whether this is a reasonable approach to divine action depends critically on the ontological status of measurement probabilities in quantum mechanics. For divine action to be consistent with the quantum laws of nature as understood in the orthodox interpretation, these probabilities must be both ontologically prior to the measurement and thus represent some feature of the system in question, and alterable by God without an intervention in the wavefunction itself (which evolves deterministically under the Schrödinger equation between measurements). It is questionable whether it is possible for these two elements to be held in tension together, and it is very unclear how this can be accommodated in orthodox quantum mechanics.

4. God Controls the Outcome of Measurement. Of course, one solution to the above problem is to claim that God ignores the probabilities predicted by orthodox quantum mechanics and simply controls the outcomes of particular measurements. This does not present us with any specific problems. However, we are again forced to accept a certain philosophical position. First, a conception of the ontological nature of measurement probabilities opposite to that for the third option is obviously required; it is necessary for the probabilities to follow *from* the measurement results and not vice versa. Second, we are again also forced to accept Tracy's conception of intermittent divine determination as opposed to the thesis that God influences every quantum mechanical event. If we accept the latter, then God is simply deceiving us by letting the probabilistic predictions we make have some bearing in reality.

The essential technical basis behind this approach is a denial that Bohr's probability interpretation of the wavefunction has any ontological priority and consequently is an approximate relationship between ensembles of identical systems for a given measurement repeated a large number of times. God then acts by determining certain quantum measurements, and the probabilities predicted by the theory include these divinely determined quantum measurements.

Final Conclusions

These four possibilities form the logical nexus for divine action consonant with quantum mechanics. As we would expect, the two possibilities related to the process of measurement offer the most potential. Indeed, it seems fairly certain from the language that protagonists of quantum mechanical divine action use in their discussions that their theses are also implicitly rooted in some kind of measurement interaction. However, no one of the possible options is without its attendant difficulties, as we have seen.

All of the proposals have their own scientific problems, and it is important that the debate be moved into a more specific consideration of the philosophical and scientific claims underlying them. Of course, the option is potentially open of combining the four possibilities in some way as to remain within the regularity of physics. If divine action did occur through quantum mechanics, it would most likely be through a combination of the above options in such a way that the divine purpose remained hidden. Yet even on this account it is not clear that we can simply sidestep the attendant difficulties; certainly it is not possible to appeal to the distinction between pure and mixed quantum states in order to facilitate this.

It is only when coupled to the large-scale macroscopic effects produced by chaotic events that quantum mechanical divine action gains any real credibility. There are nevertheless many unsolved problems in relating quantum mechanics and chaos theory, not least because of complex issues concerning the fractal intricacy of chaotic systems.[13] It is my belief that this coupling of the two phenomena would offer the most theologically satisfactory model, and it is implicit in the thought of those protagonists of special divine action in chaos theory such as Polkinghorne (Saunders 1999b, 294–97). Indeed, it is interesting to note that the previous differences of approach (i.e., the quantum protagonists against the chaos theory protagonists) explicit in the Vatican/CTNS conference series might be reconciled by the fact that *both* of these schools of thought are very reliant on quantum chaos.

From this study of quantum mechanics it seems reasonable to argue that, of all the proposals for quantum divine action, Tracy's is the most promising. The conclusion that God alters every quantum event (i.e., measurement) is not necessary to avoid the charge of interventionism. As we have seen, however, there are major philosophical difficulties that remain unresolved with the assertion that God interacts with creation through a measurement interaction.

The scale of quantum mechanical events must also be a primary consideration in our study. Certainly by altering parameters by less than their Heisenberg uncertainties, God could affect distant outcomes without violating any physical laws. However, to achieve any major macroscopic results God would have to determine a huge number of quantum processes. Consider for example the following rather absurd example. Imagine that God wishes to annihilate the dinosaurs by colliding an asteroid into the face of the Earth. If by coincidence an asteroid happened to be "naturally" going to just skim Earth's atmosphere, then God could steer it into the Earth for a collision by using quantum adjustments. Such a steering *would take approximately three million years to achieve* if no violations of physical laws occurred (Jones 1997, 122). This implies that God would have had to start steering the asteroid long before the evolution of the dinosaurs.

While this is a theologically unsatisfactory model (not least because it ignores the possibility of divine action on any part of creation other than the asteroid), it does go some way toward illustrating the scale of the control God would have to employ. If God did act regularly in quantum mechanics, then there are relatively few quantum processes that would escape such control. If this is the case, it seems very irrational that God would formulate quantum mechanics, as a product of the creation of the world, to be indeterminate.

The possibility exists, of course, of divine determination of certain key quantum processes that would later be amplified by means of chaos theory to provide macroscopic action. This possibility may seem appealing at first sight, but it is still prone to the fundamental objections raised about the nature of divine interaction with measurement. It also makes divine action very dependent on the processes of nature: God's freedom is very limited if it can be exercised only when a potentially provident chaotic chain is available to use. This seems far from the biblical description of Providence. There is an even more fundamental problem, and this concerns the nature of quantum measurements. As we have seen, it is a very interventionistic account of divine action to posit that God makes God's own measurements, but if this is not the case, then God is very much limited to the potentialities available in creation. Measurements are relatively infrequent events, and thus any theory of divine action linked to them is likely to be highly episodic in nature. Moreover, God is not able to act evenly throughout creation; only in those regions of the cosmos where a lot of measurements are taking place can God "cheat at dice."

These considerations lead me to the following conclusions. The thesis that God determines all quantum events is not only scientifically irreconcilable with quantum theory but also theologically paradoxical. There are also fundamental philosophical difficulties to be overcome if we hold to the thesis that God influences only some events at a quantum level. Moreover, the scale of the providence required for divine action through quantum mechanics is truly phenomenal: it takes millions of years of action to achieve even the most simple effects. If it is also held that human beings have free will, then this situation becomes absurd. By making quantum measurements we are determining the state of divine quantum determinations in a way that must significantly increase the already considerable amount of time God requires to achieve anything. The linking of divine action to quantum mechanics must take place by some kind of measurement interaction, and this also places God in a subordinate position to creation, and the episodic nature of measurements places severe limitations on the possible actions God could achieve. The resulting view of divine action is far from the biblical and traditional accounts of providence, and it thus seems reasonable to conclude that a theology of divine action that is linked to quantum processes is theologically and scientifically untenable.

Every time we drink a glass of water we are statistically likely to drink at least one molecule that has passed through the bladder of Aquinas himself. This truly remarkable fact follows quite simply from the assertion that there are many more molecules of water in a glass than glasses of water in the sea.[14] The revolutions science has caused in our society and our view of the universe are undeniably phenomenal. They have also caused great changes in our understanding of theological method and the questions theology poses. It is important, however, in developing a correct theology of science that theologians be true to both theology and science. Indeed, if we were to couple the proposals discussed here with a common interpretation of the quantum measurement problem, we would reach the absurd conclusion that God is often prevented from acting in the universe because of the lack of anyone to perform a measurement. This is a limitation few theologians would be prepared to accept, because divine purpose is integral to the very identity of God:

> I am God, and there is no one like me,
> declaring the end from the beginning
> and from ancient times things not yet done,
> saying, "My purpose shall stand,
> and I will fulfill my intention,"
> calling a bird of prey from the east,
> the man for my purpose from a far country.
> I have spoken, and I will bring it to pass;
> I have planned, and I will do it.
> —Isaiah 46:9–11 NRSV

NOTES

1. It is important to note at this point, however, that Aquinas did not limit divine action to indeterministic events. He argued that God acts through indeterministic causes such as human free will without the kind of interaction that the protagonists of quantum mechanical divine action consider. What Russell, Ward, Tracy, Murphy, Polkinghorne, and others have referred to as divine action "through" secondary causes, Aquinas would have called "miraculous" activity because it is extra to what normal secondary causes would otherwise achieve.
2. Arthur Peacocke's main objection to the thesis of quantum mechanical divine action arises because he essentially denies this step in the argument; his argument is based on a concept of self-limited divine omniscience which extends to limit God's prediction of the outcome of quantum events (Peacocke 1998, n. 31).
3. A quark is one of the constituents of the nucleus of the atom. For an excellent introduction to quantum mechanics see Polkinghorne 1979.
4. This exchange is as quoted in Richard Dawkins, *"Science, Delusion and the Appetite for Wonder,"* Richard Dimbleby Lecture for BBC Television, broadcast 12 November 1996.
5. For a good general discussion of what the world would be like if macroscopic objects exhibited quantum mechanical behavior, see *Mr Tompkins in Wonderland* (Gamow 1965).
6. Nevertheless, there remains the possibility that it may be replaced by another, better, science. Roger Penrose and others have argued for such a model.
7. This is one of the primary motivations for the ontological claims made about quantum mechanical indeterminacy. If our system consists of *n* particles, the wavefunction at any particu-

lar time is in a space of *3n* dimensions and not simply a space of 3 dimensions. Thus, the wavefunction and Schrödinger equation do not single out any one possibility.

8. Crucially, von Neumann's approach to quantum measurement is not a simple codification of Bohr's position. Von Neumann proceeded from the assumption that *all* phenomena were describable by quantum mechanics and thus denied Bohr's attempt to place quantum phenomena into a classical framework.

9. For more on the relationship between miracles, special divine action, and philosophy of science, see Saunders 1999b, chap. 2.

10. It is interesting to note the influence of Karl Heim (1953) on William Pollard. Heim prior to the publication of Pollard's work had already made an explicit connection between quantum mechanics and providence on the basis of Matthew 10:29. Pollard was certainly aware of this work, as he critiques Heim's view of the relationship between God and nature as being nonbiblical (Pollard 1958, 26–27). Pollard remarkably did not make any comment on Heim's other assertions despite the similarity of his own position to this work.

11. This is as opposed to the claim that the probabilities reflect the distribution of the results of a series of measurements.

12. The basis of this claim can be found in Heisenberg's interpretation of the probabilities in measurement theory as being an analog of Aristotle's notion of potentiality. The most thorough development of Heisenberg's position can be found in the work of Vladimir Fock, who emphasized that the probabilities in question belong to the individual quantum entities themselves and identify its potential possibilities. On this approach the manipulation by God of these probabilities is fundamentally interventionistic, for it changes the nature of the entities themselves.

13. In particular, there are substantial difficulties with the notion of the input of "active information" in chaos theory because of the fact that the real world cannot embody the fractal intricacy this concept relies on. This raises a fundamental objection to divine action through chaos theory quite aside from the widely discussed issues of determinism which all critiques have hitherto relied on (Saunders 1999b, chap. 5).

14. This remarkable claim was developed by Professor Lewis Wolpert.

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