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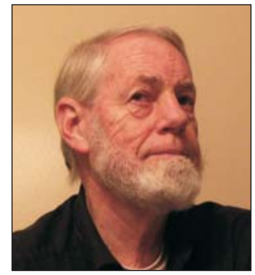

Dillard W. Faries

A Personal God, Chance, and Randomness in Quantum Physics

Dillard W. Faries

Using simple games of chance, we will see the challenge that chance and quantum physics present the theologians of physics. Our games avoid all higher mathematics and have experimental basis. They are not just Gedanken experiments. I hope they can leave us with "no excuse whatsoever,"[1] at least to deal with the issues. Unfortunately for all of us, physicists, metaphysicians, and theologians, we must think very carefully. I will tell you the story; you (or hopefully some good theologian) can do the careful thinking. Our two games of chance will be a million-dollar lottery and a revised game of Battleship™.

> One way or another, God has played us a nasty trick … Physicists may glory in the challenge of developing radically new theories in which non-locality and relativistic space-time can more happily co-exist. Metaphysicians may delight in the prospect of fundamentally new ontologies, and in the consequent testing and stretching of conceptual boundaries. But the real challenge falls to the theologians of physics, who must justify the ways of a Deity who is, if not evil, at least extremely mischievous.
>
> Tim Maudlin, at the end of his book *Quantum Non-Locality and Relativity*[2]

You will hear the whole range of reactions to chance. Within the last century, science, especially quantum mechanics, thinks that it has something to say about chance. I am sure that it does, and I am equally sure that a brief article cannot do it justice. Maybe we can at least stimulate some hard thinking.

Here is the rub: the general belief in quantum physics is that chance is absolutely fundamental and inextricable in nature and that we as knowers cannot penetrate that boundary. In philosophical terms, we might say that chance is not only epistemological but also deeply ontological. In theological terms, we might say that God turns some (or all?) of nature over to a chance mechanism and does not allow us to see its inner workings. If God is a person who maintains control of his universe, we might then be forced to accept this statement: God plays dice and he tosses them where we cannot see them. This is why an on-looking world may accuse God of evil, mischief, or deceit, as you will find in our opening quote by Tim Maudlin and our closing quote by David Albert. The sore spot of God and chance gets rubbed raw when one considers the following story (revised from an original Russian *anekdot*):

> In a state university city of Middle America, a restaurateur offers a chance for a free tattoo for every $25 purchase. You only have to guess the spot-count on his roll of two dice. Bubba and his buddy take the bait.

Dillard Faries *is Professor Emeritus of physics at Wheaton College and a long-time member of ASA, with degrees from Rice and Berkeley. His early research was in nonlinear optics; his present interests focus on foundations and history of quantum physics and its theological and philosophical ramifications. He and his wife Sally have three children and six grandchildren.*

> Restaurateur: What number do you choose?
>
> Bubba: Seven.
>
> The restaurateur turns his back, rattles the dice, throws them out of the customers' sight, picks them up and shows a 6 and a 2. "Sorry," he says. "Try again next time."
>
> Bubba's astute buddy is a skeptic. "That's fixed," he says. "Nobody can win against that guy."
>
> Bubba: No, you're wrong. Our quarterback won twice last week.

Any resemblance to real people, dead or alive, hired or fired, undiscovered or sanctioned by the NCAA, is purely coincidental.

The two most famous quantum physicists sparred or joked on the "theological" issue.

> Einstein: I cannot believe in a God who plays dice with the universe. *Der Herrgott würfelt nicht.*
>
> Bohr: Who are you to tell God how to run his universe?

Whether one hearkens to a Spinozan God (Einstein's view that God is Nature and Nature is God) or to a Creator, Sustainer, controlling God, the natural identification of the big questions with the Old One, with the One, or whatever we call him leads to cross-talk between fundamental physics and theology. Questions about reality, randomness, locality, and causality, all in the disguise of philosophy or physics, are about the ultimate nature of God and/or his creation, God's personhood, his control of nature, his omniscience, and his omnipotence. As Maudlin (quoted above) recognizes, the real challenge is theological, and it is no surprise that great physicists recognize that they are treading on holy ground. Einstein's concern about chance entering the world is clearly a worldview, theological objection; even though he probably did not remove his shoes, he was likely wearing no socks.

Although physicists may easily banter about God, theologians have generally been more circumspect in their pronouncements about physics. Even though he may think he sided with the great Albert Einstein, R. C. Sproul's venture into questions of chance may constitute rushing in where angels fear to tread. To give only one quote: "If chance exists in any size, shape, or form, God cannot exist. The two are mutually exclusive."[3] After seeing the challenges of quantum mechanics briefly here, you can be a better judge, at least of the complexity of the issue.

The Outer Chamber of God's Casino: A Lottery in Space and Time

Atomism brought a mild form of chance into physics. Newtonian physics developed such a thorough description of change as merely matter in motion that Laplace could envision a super-intelligence who could calculate and therefore know the complete history of the universe, backward and forward, with "no need of that hypothesis [God]."[4] A God of complete determinism becomes an impersonal God of complete law and order, one whose supposed connection to the universe becomes a moot question. Einstein understood and accepted this kind of God. The complexity of our world reduced to such simplicity left him in awe of the mysterious, subtle, yet nonmalicious God. Atomism, more specifically the very large number of little pieces of nature, meant that we, somewhat below the Laplacean super-intelligence, could not have that complete knowledge and/or control of even small portions of the universe. We had to rely on statistics, the calculations of apparent chance based on our ignorance and limitations. One of Einstein's papers of his *annus mirabilis* (1905) confirmed these atomistic statistics in calculations of Brownian motion, the jiggling of microscopic particles caused by the collisions of invisible submicroscopic molecules with the much larger visible chunks.

Radioactivity, discovered (by others) when Einstein was in his teens, introduced a deeper level of chance. Individual events could be seen because the energy was a million times that of atomic energies. We could not (and have not to this day) been able to predict when such an event will occur. We are still ignorant; statistics still allows calculations, but we cannot pretend to have any deterministic model. We can pretend that such a model exists and/or that God is in complete control on a level that is inaccessible to us. The causes, if there are causes, for an individual event appear to be internal and inaccessible because we cannot do anything to change the statistics. Chance, formerly introduced for intentional ignorance in games of chance or for practical ignorance in the case of the statistical mechanics of an impossibly large number of atoms, started to look as if it were hidden deep down inside the nucleus.

Another of Einstein's 1905 papers had introduced atomism into light, what we now call photons. The earliest quantum theory of atoms (Bohr, 1913) arose from the question of how atoms, with some kind of electron motion, produced light. Classical theory said that an orbiting electron in an atom of the known size would radiate light waves and collapse from loss of energy in about ten nanoseconds. Niels Bohr, astutely noting that our universe seemed to last a lot longer than such a predicted demise, postulated that specific states (such as certain exact orbits) were at least reasonably stable (called stationary states) and that light was emitted or absorbed only during jumps between states. There was a lowest state (lowest in energy and smallest in size) which could be a completely stable state (if no light came to kick it up to higher states) keeping the universe from total collapse. We call these various levels quantum states. Jumps between levels of many atoms produced a combined set of light waves, electromagnetic waves which had also become quite well understood.

At that time Bohr did not believe in photons, the atoms of light, so the full force of atomism did not strike him. Einstein, a sometimes lonely believer in the photon, saw something different and saw problems which were to come to fruition only later (mid-1920s) with a fuller development of a complete quantum theory. Bohr could envision the pay-out of energy from atoms in a continuous fashion, emitted throughout a transition. Einstein saw the grand jackpot: there is a full pay-out of a photon or there is no pay-out. Atomism has two sides: it explains semicontinuity by the large numbers involved in our ordinary macroscopic world, but when you get down to this size, it divides no further. An atom in transition does not dribble out small amounts of energy in all directions over some period of time. It gives up the whole transition energy to a *particle* of light which flies off in some direction at some instant of the jump between states. Einstein was seeing the conflict and consequences of what became wave-particle duality. Waves, a continuous transmission of energy, may be thought of as very many particles in some coherent pattern, but when you get down to one particle, it cannot reasonably behave like a wave. It is a clump; it is or it is not; it is indivisible.

Einstein saw that when you get to that indivisible level, it was going to act like a lottery. An exact complete result will occur, but we will not see the inner workings of the chance mechanism. As much as he struggled against the ad hoc style of Bohr's model of the atom, he found amazing confirmations by his own methods. In 1917, he worked out a formula for the thermodynamic equilibrium of atoms and light. To do so, he used the concept of spontaneous emission of light, basically granting that atomic emissions of visible light *might* follow the same seemingly random pattern of the apparently causeless radioactive emissions of nuclei. Combining this with stimulated emission[5] and absorption, Einstein reproduced the famous Planck formula[6] of 1900, which had been the basis for his 1905 paper on the quantization of light, the hypothesis of photons.[7] The atomic emission of light suddenly looked like nuclear radioactive emissions, at least in its statistical nature. He was forced to deal with chance up close and personal.

Chance is inevitable, simply a part of our experience when we have incomplete knowledge. We do not know, so our best understanding involves figuring the odds. Chance of this kind may be *choice* when the entity freely but inscrutably exerts its will, an internal unsearchable process for the outside observer. Chance of this kind could also be *grace*, the free and inscrutable choice of a controlling external agent. It could also be a *lawful* result, the end product of some recipe which remains hidden to us. It could also be *random*, as causeless and unpredictable as we can imagine. But if it is a singular undivided event—as the indivisible particle seems to require—the choice, or the gracious decision, or the lawful result, or the random deed is a done deal; the real particle of a certain kind goes off in a particular direction and makes itself available for detection by some observer. That is how Einstein saw it, a sharp reality for which we have only a fuzzy picture. Our camera, our knowledge, our theory is limited, but Nature (or God) is complete. Choice at a particle level (a nod toward panpsychism), grace (a nod toward a deity), law (a nod toward a hidden Newtonian/Laplacean determinism), or a random act (a nod toward chaotic anarchism) would remain a choice for the theorist, and Einstein would clearly lean toward deterministic law. We should note that a God who is vulnerable and willing to give up his high position, knowledge, and control is perfectly consistent with any of these.

Einstein's belief in the particle of light led him in the direction of determinism, but in the same paper (1917), he gave the impetus for a different direction, a direction in which quantum mechanics actually developed. He realized that the electromagnetic field value (squared, if you are willing to go to such higher mathematics) gave the probability of a photon at that location. With many photons, it gave a density of photons, but when you get down to the indivisible *one* photon, it gave probabilities. Places with larger electromagnetic fields had greater chances of having a photon. Rather than being a single probability decision which determines an event, probability could now go on the road. When quantum mechanics developed a wave equation for Ψ, a wave of inscrutable ontology (i.e., we do not know what it is), Max Born harked back to Einstein's understanding of electromagnetic fields as probability of the electromagnetic particles and interpreted Ψ as a probability wave.

God's Lottery

Imagine an atom in an upper energy level, ready and able to radiate energy which, in fact, is detectable as a single photon at some time at some place on a spherical surface surrounding the atom. The photon is detected at a certain point (on a sphere of radius R) at a certain time by a flash on the fluorescent screen. That is a reality we can all agree on. Einstein says that we can infer a reality of a decisive event called emission at an earlier time (earlier by R/c) for a photon traveling at speed c along the radial line. The decision may have been choice, grace, hidden law, or randomness, but it was a done deal back then. That is faith, a belief in a reality which can earn Einstein the claim (made by others) of representing a traditional monotheism (because Nature was God and God was Nature). The agnostic could have been represented by Bohr by means of a simple statement of ignorance: we know a flash occurred, but we do not know what happened before.

You can see how unsatisfying and how hopeless that feels; we think that we have to try to understand *something* and fill in the blanks. Thus a most fanciful story was invented. A wave Ψ propagated out from the atom. It is not just our knowledge (incomplete as it is in the representation of mere chance), but it is the photon in limbo, going by way of all possible paths from the atom outward. Every point in space has a traveling lottery passing through it, seeing which place and which time will be the winner, i.e., producing the flash of a decisive event. This scenario is also a matter of faith: a negative faith that the particle *does not exist* as Einstein envisions before the measurement, and a positive faith that it has some other form which we call superposition, a multiple identity in space and time. Ψ behaves lawfully as it propagates, but somehow collapses to a point in space and time. Because we can make no pictorial or lawful model of this collapse, we consider this to be a measurement problem. But it is an article of faith of the orthodox belief structure of quantum mechanics. For Bohr and the so-called Copenhagen interpretation, the flash tells you the immediate future and a starting Ψ for a lawfully determined evolution of Ψ in the future, but it does not tell the past. For Einstein, it was the real manifestation of a previous lottery which was the particle's creation.

I call this faith on Einstein's part, but it was not faith without reason. He had a reasoned argument against the existence of lotteries which can propagate but have indivisible prizes. If we have a million possible detectors out on the fluorescent screen at radius R, there is one chance in a million for each of them. In Einstein's picture, the atom hands out envelopes to one million recipients who carry them out to R. At the fluorescent screen, each of the one million envelopes is opened to see if it might be the *one and only* fluorescent flash, the indivisible $1,000,000 prize. The lottery was at the beginning, the winner was determined (though unknown), and it all propagated accordingly.

It was also faith on Bohr's part, and Einstein saw the problem. In Bohr's scenario, each of the million participants gets a full-fledged lottery machine which does not actuate until the measurement. Each one has a one-in-a-million chance when it gets to the screen. But what if two people win? That is no problem if we are turning in winning tickets and later determining that we can split the pot. But here there is *one* prize and it is instantaneous, a fluorescent flash now. Einstein saw that this is impossible because a win at one point must instantaneously exclude all possibilities of winning elsewhere. This required what he called spooky action-at-a-distance, *spukhafte Fernwirkung*. This was not just spooky; it violated his relativity principle, the finite speed limit of the universe, the speed of light. This was an absolute higher principle which claimed his faith.

If the decision is made at the start and reality ensues, the decision could have been choice, grace, law, or randomness. Randomness in the sense of independence from all external parameters is impossible to extend in space and time; it would have to be dependent on what occurred at other points, shutting off its chances if there was a winner elsewhere. Bohr convinced the physics community that it was one unified system which worked so as to give the result, but he gave no mechanism for the effective instantaneous connections.

We should be clear that quantum mechanics does not always claim a limbo state in every system. There are *pure* states which will give certain answers, in the simplest case a straightforward "yes" or "no." A pure state is what is produced by a measurement. Thus a nondestructive measurement converts a limbo state (uncertainty) into a pure state (certainty), and an immediate remeasurement will get the same result. The famous Heisenberg uncertainty principle specifies both qualitatively and quantitatively when limbo states must exist. *Incompatibility* of two measurements means that a pure state of one measurement (possible to prepare by making that measurement) is always a limbo state of the other measurement. The formalism of quantum mechanics makes it possible to describe mathematically which measurements are incompatible and to calculate the probabilities and statistics of the uncertain states. Einstein would agree that you and I may not know, but he insisted that when we measure and get a value that this is a real value of a pre-existing condition. They were arguing about an unmeasured past, and you cannot decide.

But Einstein fought for years and finally came up with a clincher, he thought. To get two independent measurements, you can use twins which are separated. Measurement on one gives 100% certainty on the other one, making that aspect as real as you can make it and yet independent of the act of measurement. Measuring property A on the right means the value of A is known on the left. The measurement of property B on the left gives the value of B on the left (and the right). There are thus real (100% certain) values of both A and B, real quantities which quantum mechanics does not give and does not know. Thus quantum mechanics is incomplete. The reality is not at fault; our theories and knowledge are just limited and fuzzy. Chance and randomness are our lack of knowledge. This paper of 1935 is so famous that it is known simply as EPR (Einstein, Podolsky, and Rosen, the authors).[8] The original paper dealt with the famous incompatible measurement of position and momentum; a simplified example using spins or polarization, called EPR-Bohm, is usually used because they are the simplest systems, being only two-valued. Thus the basic nature of such realities can be handled with a continuum of questions (directions along which polarizations or spins are measured), each of which has only two answers; a basically true/false exam is available for such a system.

Even though Einstein died first, the questions and lack of acceptance from his good friend haunted Bohr to his death in 1962. We have transcripts of an interview conducted by Thomas Kuhn the day before Bohr's death and drawings on his blackboard remained when he died. Einstein is not to be ignored lightly; Sproul, certainly lacking in scientific reasoning and arguments, chose a good running mate.

Into the Inner Sanctum of God's Casino

Independent of Sproul's hard-line theological argument (which I do not find appealing), Einstein's reality, our incomplete knowledge, and absolute speed limits in the universe are pretty convincing. Quantum mechanics' asymmetric time (a collapsing wave-function upon measurement) appealed to William Pollard. He thought that physics had finally discovered historical and personal time which is central in the Judeo-Christian tradition.[9] Many Eastern traditions maintain a cyclical time based, for example, on recurring phenomena such as seasons and reincarnation; physics had settled into an abstract directionless time represented by a simple one-dimensional line in Cartesian coordinates. The Judeo-Christian tradition affirms directional time given by a history of God's interaction with his people, coming from a beginning and going to a culmination. Asymmetric time may be nice, and it may be right, but my sense of symmetry in the abstract time of physics and my belief in a symmetry of causality and teleology draw me back. Whether we are Christian or not, Einstein's hard-rock reality is attractive to many of us, even if it might be a misguided throw-back to Newtonian-Laplacean determinism.

In a 1932 book on *The Mathematical Foundations of Quantum Mechanics*,[10] John von Neumann, a mathematician with an immense reputation, proved that a hidden-variables formulation (an underlying lawful determinism) was impossible. To keep us from taking mathematical proofs too seriously, it is fortunate that David Bohm, clearly under the spell of Einstein's questioning, proved von Neumann wrong by producing such an impossible formalism (1952).[11] Neither Bohm nor Einstein seemed to take it seriously as *the* way that reality was; it was "too cheap" a solution.[12] After his discovery of a deterministic formulation, Bohm still defended the occurrence of chance and the fall of classical causality in his 1957 book.[13] But the possibility of determinism kept Einstein's skepticism alive in the physics community. John Bell, appalled to find that a favorite book by Max Born[14] (from a set of lectures from 1948 but published later) had completely ignored the significant Bohm achievement, took up the challenge with clear sympathies with Einstein.[15] He produced a theorem[16] about the EPR-Bohm experiment which may prove to be the most significant theorem of twentieth-century physics. It is widely touted as proving that Einstein was wrong. Whether it is ultimately convincing or conclusive, I believe you will find it powerful. Hold your objections in abeyance please and try another level in God's casino, a variant of a good children's game.

Battleship™

The game of Battleship™ involves secret placement of an array of ships on a 2-D grid. Contestants alternately fire at particular squares seeing if they can destroy their opponent's ships. The game continues until only one person has some undemolished ship(s). Let me invent a quicker 1-D version suitable for gambling and for comparing our commonsense real world with the real quantum world. Our 1-D array contains the 60-minute markers around the circle of a clock face (fig. 1). Place 30 ships in the 60 places with two rules: (1) spaces 180° apart (30 minutes apart) must be the same (both occupied or both unoccupied), and (2) spaces 90° (or 270°) apart must be different (one occupied and one unoccupied). See figure 2 for one possible placement.

Figure 1. No ships placed.

Figure 2. Very poorly placed ships with many boundaries.

Now the purpose of the game is to find the unprotected flank, a boundary where one shot hits a ship and the adjacent shot finds only water. One person (the house for gambling purposes) prepares the array and the other chooses two adjacent spaces to try for a win. One double shot and the game is over, win or lose.

Analysis: The house/preparer would like to group ships as much as possible to limit the boundaries (although generous parents might place ships alternately around the circle to give their child 100% chance of winning). The house strategy is then to have 15 ships on one side, 15 on the other with four boundaries in the 60 possible choices (fig. 3). There is no strategy (short of cheating) for the player who shoots; you simply choose (randomly) among the 60 choices. You can choose to play or not based on the odds and the pay-out. The chance of winning is clearly limited to no less than 1 in 15 (4 in 60).[17] Anything better than $15 pay-out for $1 paid to play should be good, a money-maker in the long run.

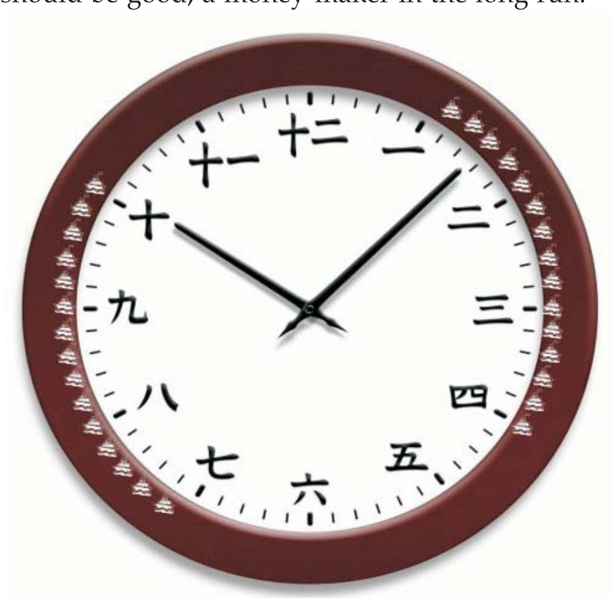

Figure 3. Good placement of ships with only four boundaries.

God's Quantum-Mechanical Battleship Machine

Let us see how God plays this game in the quantum world. Entering the casino we see a simple black box labeled BATTLESHIP with two dials (arrows that can be pointed to each of the 60 minutes around the face, a button, and a light for each dial which flashes *gray* (for striking a ship) or *blue* (for striking water). To play, set the dials to two adjacent positions, push the button, and see what the lights do. $1 to play, $25 pay-out for a win, i.e., different lights.

Good pay-out, but a committed choice first and a hidden machinery sounds too much like our restaurateur. The guardian angel sees our hesitation and offers to allow us to check that it abides by the rules for free. Try only one dial as much as you want; you find that it comes up 50-50, *blue* and *gray* like heads and tails on coin tosses. Try two dials with differences of 0°, 90°, 180°, and 270°, and you will always get the appropriate coincidences and anti-coincidences. Seems fair and it checks out.

OK, $225 gives us 225 plays and expectations of 15 wins and a pay-out of $25 x 15 = $375, a net gain of $150, not bad for one hour.

I know the quantum mechanical version and its answer so I simulated it on the computer. My first try, the results were as follows:

Blue-blue	*Gray-gray*	*Blue-gray*
113	110	2

Rather than making $150, I have lost $175. I feel cheated, and I feel bad that my first thoughts were of that restaurateur. It may be hard if you are a confirmed monergist or theistic determinist, but I, at this point, want to separate God the person from a god somehow running this machine. I want to preserve personhood and suppose that this machine has some independence, specifically some independent way of cheating me.

Since I had my computer simulation set up, I could play repeated sets of 225 games by merely punching a few buttons. I played many times and on a few occasions won six or seven times. Even with seven wins in 225 tries, I am losing $50. It was not a statistical fluke that I won only twice in my first 225 games. Any capable physicist should immediately recognize the quantum mechanical situation of polarizations of two twin photons. We say their polarizations are entangled. We should be able to tell you the formula for coincidences (and the left-over anti-coincidences); we should even be able to tell you that the win rate should be $\sin^2\theta = 1 - \cos^2\theta$; since I chose 6° (which is about 0.1 radian), we should be able to calculate in our heads that the win rate is about 1%, almost seven times smaller than our estimate.

Let us take an honest look at what we are saying. We are saying that if you or I or God prepares in any way the value (*gray* or *blue*, *ship* or *water*) for each of the 60 positions and we try our hand at finding a boundary, we will have *at least* 1 chance in 15. I mean that they can be chosen by the photon or atom, they can be given or simply known by God, they can be specified by some recipe which we call a law of nature, or they can be randomly generated. This prepared reality will always offer odds better than 1 in 15. Yet this quantum mechanical machine beats you, badly. Predetermined answers will not work. You can begin to see why the limbo state, a state which *does not* have the answers in advance, is looking as if it is necessary.

Let me be clear that we are not facing a problem with *only* a theory, or with *only* its interpretation. The theory gives us the answer readily, but it could be wrong. The interpretation may be wrong about some inner workings that are, in fact, inessential. But we are talking about what happens in quantum experiments which have been confirmed with a series of subtle refinements.[18] This is a statistical *reductio ad absurdum* argument. In mathematical proofs, we start with some givens, we make logical steps, we get to absurd results, and we know that the givens must be wrong. Here we start with givens (*any predetermined* answers to sixty 2-value questions), we calculate odds, and we go to nature and find that our odds are absurdly wrong; therefore we know that those sixty given answers *cannot be pre-given*. Period. Each and every question (Do I hit a *ship* or *water* with a shot at this position?) receives an answer if and when it is asked. But no one, not even God, could have predetermined or known *all* of the answers beforehand. Here is a simple case in which God simply does not have *all* the answers. He always gives a simple answer, *blue* or *gray*, *water* or *ship*, to the question we ask; he does not answer the questions we do not ask, simply not having the answer. This is strong talk, and I hope you will join me in being disturbed by it.

Let us go back to the machine because we have left God and the restaurateur plenty of opportunity to cheat us. Please let us see the dice rolling; let us have an auditing firm independently see the answers and our probing questions.

Step one: look in the machine and find two pathways from the back of the machine, each divided at the dial in the front: one branch producing a *gray* light, one a *blue* light in each case. We can surmise a real beam of particles but also check it by systematically blocking pathways. The beam takes some time to go from the back to the front. We can lengthen the time by putting the supposed twin source much further back, push the button first, and then make our choices. This is not easy because the velocity of light is large, but it does not matter. We still get the same results.

Step two: the beam from the back could just be a trigger and carry no information; the dials in front are close to each other and can be set to give distributions based on each other's settings. OK, separate the two dials by large distances, collude on the settings but do not set them until the source beam is on its way and no time is allowed for any signal to let the dials know about the other one. Good try, but no, it does not matter. The results are the same.

We are stuck. We have eliminated the possibilities of local collusion. We know that *any means* of having the answers prepared leads to contradiction. The only solution seems to be that something which lacked specificity in its *being* has some true *becoming* according to statistical odds, odds which are capable of having nonlocal links which are impossible to envision in our physical world. Except for the stretch to get a mechanism for the nonlocality, the orthodox quantum mechanician is happy and vindicated. The lack of specificity is the superposition of states, the ability to live a divided life, with various potentials of being which are actuated at the act of measurement. The nonlocality is just a manifestation of the inseparability of nature, the requirement to look at the whole system, puzzling as that may become. Theologically, this is also satisfying if you believe in a God who is vulnerable to chance, free-will, and even rejection; if you believe in a life of becoming, a historical arc; if you believe in a nonlocal nonconfined God; if you believe in a God who lets nature cooperate with him. However, if you believe in a God who has tied everything into a tightly deterministic system—what physicists would call a block universe—you cannot be very happy with this.

Let us say clearly that there is no argument against the concept that everything that was, that is, and that is to come was fully ordained and determined by a person we call God, even if the whole universe *was* total chaos, *is* totally random in appearance, and *is* totally lawless *to come*. It, the complete determination by God, is an explanation which explains nothing because it explains everything by the same single word. I can only say that, for me, it saps God of personhood and meaning. But if you find meaning in a strict determinism, let me loosen the noose for you, as a matter of honesty and with as clear thinking as I can muster.

Our argument focused on some things we call particles and their properties, answers to sixty *blue-gray* questions. We concluded that the properties were not fixed, that they came to being as chance events which were somehow guided in their relationship by nonlocal effects. We said nothing about their beginnings, or their ends, or—to say it in physics language—their detection before or after their creation and annihilation. We said that we push a button and something comes out; we put a discriminator in the path, dividing *blue* from *gray* and we get a detection, a *blue* or *gray* light flashes. If our argument holds, these detection processes are also chance processes which might have nonlocal influences. How many things, which we know nothing about, are coming from the source or to the detector, and what nonlocal effects or instruction sets determine which ones we will see? One can, of course, go further and include our eyes, our mind, *ad infinitum.* I suppose that, whatever your belief or disbelief, you may squirm into or out of any argument.

You will have to do your own clear thinking, but let me clarify two fine points:

1. I have said that *all* of the questions cannot have their answers predetermined; they cannot have that reality in any form. This does not mean that *none* of them can be real and determined. Because we can delay the choice of measurement until a particle is on its way, we think that all questions are equal. But we cannot deny the possibility of a determined reality before the measurement, of the result which is obtained by the measurement. This is clearly possible; it happens. The unmeasured are unmeasured, and we cannot argue about a hypothetical "what if?" But something which is measured, and thus determined, could have had that reality before.

2. Since all questions are open to us, predetermination or pre-paration must apply to all questions equally. Our sense of causality takes a simple form: when the dial set at nineteen produces a *blue* light flash, it was *because* there was no ship at position 19, we (and Einstein) think. The wholesale pre-paration is impossible, producing contradiction, but the specific post-paration for position 19 is possible. As hard as it is for us to consider teleology, i.e., causality of the future, going toward a *telos* rather than from a cause, it is a possibility. In terms of our relationship to God, we might say that "God does not answer *unless* we ask" is not the same as "God does not answer us *until* we ask." We may not know the reality of the answer until we ask, but the reality may have been on the way all along. God's foreknowledge and pre-paration may be accompanied by rear-knowledge and post-paration, and the nature he produces may participate in all of these.

There are no slam dunks in our understanding of nature and God, and even slam dunks are not 100% certain. Sproul puts God vs. chance as gambling stakes; to him, you either win God or chance, which is a complete loss. I am actually rather excited about a God who is vulnerable, playing the game of chance, who allows me, a chancy fellow, a chance with him, who is the Lord of becoming as well as being, a God who maintains a unitary universe, a God who draws us toward the future as well as sending us from our past, a God who can hold together the two ontologies of particle and wave, the workings of continuity and discontinuity, the deterministic lawfulness and chance occurrences, and the divinity and humanity of a man called Jesus. But I will not toss my God into any gambling pot based on how we understand the physical world.

A thoroughgoing physical determinism blossomed in the Newtonian mechanics and still holds appeal to both God-fearing and God-denying people. Bohm introduced a deterministic formalism of the otherwise standard quantum mechanics (with the nonlocality feature clearly in it). David Albert is a foremost proponent of Bohm's deterministic proposal, without having a theological ax to grind, to my knowledge. He says:

> [I]f this theory [Bohm's interpretation] is right (and this is one of the things about it that's cheap and unbeautiful, and that I like), then the fundamental laws of the world are cooked up in such a way as to systematically *mislead* us about themselves.

> [This becomes] an absolutely low-brow story about the world … that's about the *motions of material bodies*, the kind of story that contains nothing cryptic and nothing metaphysically novel and nothing ambiguous and nothing inexplicit and nothing evasive and nothing unintelligible and nothing inexact and nothing subtle … in which the whole universe always evolves *deterministically* and which recounts the unfolding of a perverse and gigantic conspiracy to make the world *appear* to be *quantum-mechanical*.[19] [Albert's emphases]

You pay your money and you take your choice, that is, if God is willing to take a chance and give you a choice.

Conclusion

Quantum mechanics gives chance and indeterminism a prominent place in the pantheon of science, changing the view that repeatability is a keystone of science. It thus has had a strong influence in our cultural worldview and therefore impinges on our theology with some strong evidences. It is quite appropriate that our theology should speak strongly back to physics, producing some legitimate "theologians of modern physics." In doing so, we cannot afford to offer easy answers out of our ignorance of physics. You will have to arrive at your own conclusions. Think hard; think carefully; help us all.

Acknowledgments

I am indebted both to an enormous literature and to individuals too numerous to list. The references below will lead you to most of them. My special thanks to students who provided the stimulus for me to make a continuing effort to understand what I can.

Notes

[1]With apologies to St. Paul (Romans 1).

[2]Tim Maudlin, *Quantum Non-Locality and Relativity: Metaphysical Intimations of Modern Physics* (Malden, MA: Wiley-Blackwell, 2011).

[3]R. C. Sproul, *Not a chance: The Myth of Chance in Modern Science and Cosmology* (Grand Rapids, MI: Baker Books, 1994), 3.

[4]Widely quoted, e.g., W. W. Rouse Ball, *A Short Account of the History of Mathematics* (London: Macmillan, 1924).

[5]Stimulated emission, the SE in LASER, is the basic idea for the laser, an idea which required more than three decades to gel and more than four decades (from 1917) to come to fruition.

[6]The formula for black-body radiation which was the start of the quantum revolution, introducing Planck's constant, h, as one of the universal constants.

[7]In spite of the dramatic success of relativity, it was this 1905 paper on the photoelectric effect which was cited by the Nobel committee for Einstein's Nobel Prize.

[8]A. Einstein, B. Podolsky, and N. Rosen, "Can Quantum Mechanical Description of Physical Reality Be Considered Complete?," *Physical Review* 47 (1935): 777–80.

[9]William G. Pollard, *Chance and Providence: God's Action in a World Governed by Scientific Law* (New York: Scribner, 1958).

[10]J. von Neumann, *Mathematical Foundations of Quantum Mechanics* (Princeton, NJ: Princeton University Press, 1955). The German original was published in 1932.

[11]D. Bohm, "A Suggested Interpretation of Quantum Theory in Terms of 'Hidden' Variables," *Physical Review* 85 (1952): 166–93.

[12]Einstein letter to Born of May 12, 1952: "That way [Bohm's deterministic reinterpretation of quantum mechanics] seems too cheap to me." Quoted by Jeremy Bernstein, *Quantum Profiles* (Princeton, NJ: Princeton University Press, 1991), 66.

[13]D. Bohm, *Causality and Chance in Modern Physics* (Princeton, NJ: Van Nostrand, 1957).

[14]M. Born, *Natural Philosophy of Cause and Chance* (New York: Dover, 1964), publication of the 1948 Waynflete lectures.

[15]"I feel that Einstein's intellectual superiority over Bohr, in this instance [EPR discussion of local reality and correlations in quantum mechanics], was enormous; a vast gulf between the man who saw clearly what was needed, and the obscurantist." John Bell, as quoted by Jeremy Bernstein, *Quantum Profiles* (Princeton, NJ: Princeton University Press, 1991), 84. Despite his sympathies, Bell continues, admitting "it is a pity that Einstein's idea doesn't work. The reasonable thing just doesn't work."

[16]J. S. Bell, "On the Einstein-Podolsky-Rosen Paradox," *Physics* 1 (1964): 195–200. His collected papers on quantum philosophy are published as *Speakable and Unspeakable in Quantum Mechanics* (Cambridge: Cambridge University Press, 1987).

[17]It is unbelievable but these few lines of simple analysis get at the core of Bell's justly famous theorem. There are clearly some generalizations and more mathematical forms, but the core idea is simply that our simple local causal reality, what we call "common sense," has certain very well-defined limitations, expressed here as a limit on the odds. Many similar examples, expressed as mathematical inequalities, are referred to as Bell's inequalities. They do not need to make mention of quantum mechanics, but gain their significance by the fact that quantum mechanical systems do not obey these inequalities. They thus expose the "uncommon sense" of the real natural quantum world.

[18]For a reasonable set of references, see, e.g., G. Greenstein and A. G. Zajonc, *The Quantum Challenge* (Boston, MA: Jones and Bartlett, 2006), 289. Early experiments in the early 1970s by Clauser, Horne, Shimony, and Holt have been followed by more sophisticated tests by Aspect et al.

[19]David Z. Albert, *Quantum Mechanics and Experience* (Cambridge, MA: Harvard University Press, 1992), 169.