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# Faith and Quantum Theory

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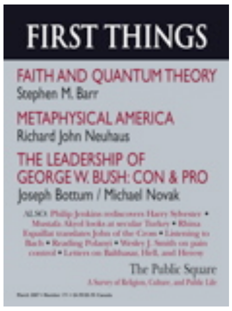


Quantum theory is unsettling. Nobel laureate Richard Feynman admitted that it “appears peculiar and mysterious to everyone-both to the novice and to the experienced physicist.” Niels Bohr, one of its founders, told a young colleague, “If it does not boggle your mind, you understand nothing.” Physicists have been quarreling over its interpretation since the legendary arguments between Bohr and Einstein in the 1920s. So have philosophers, who agree that it has profound implications but cannot agree on what they are. Even the man on the street has heard strange rumors about the Heisenberg Uncertainty Principle, of reality changing when we try to observe it, and of paradoxes where cats are neither alive nor dead till someone looks at them.

Quantum strangeness, as it is sometimes called, has been a boon to New Age quackery. Books such as *The Tao of Physics* (1975) and *The Dancing Wu Li Masters* (1979) popularized the idea that quantum theory has something to do with eastern mysticism. These books seem almost sober today when we hear of “quantum telepathy,” “quantum ESP,” and, more recently, “quantum healing,” a fad spawned by Deepak Chopra's 1990 book of that name. There is a flood of such quantum flapdoodle (as the physicist Murray Gell-Mann called it). What, if anything, does it all mean? Amid all the flapdoodle, what are the serious philosophical ideas? And what of the many authors who claim that quantum theory has implications favorable to religious belief? Are they on to something, or have they been taken in by fuzzy thinking and New Age nonsense?

It all began with a puzzle called wave-particle duality. This puzzle first appeared in the study of light. Light was understood by the end of the nineteenth century to consist of waves in the electromagnetic field that fills all of space. The idea of fields goes back to Michael Faraday, who thought of magnetic and electrical forces as being caused by invisible “lines of force” stretching between objects. He envisioned space as being permeated by such force fields. In 1864, James Clerk Maxwell wrote down the complete set of equations that govern electromagnetic fields and showed that waves propagate in them, just as sound waves propagate in air.

This understanding of light is correct, but it turned out there was more to the story. Strange things began to turn up. In 1900, Max Planck found that a certain theoretical conundrum could be resolved only by assuming that the energy in light waves comes in discrete, indivisible chunks, which he called quanta. In other words, light acts in some ways like it is made up of little particles. Planck's idea seemed absurd, for a wave is something spread out and continuous, while a particle is something pointlike and discrete. How can something be both one and the other?

And yet, in 1905, Einstein found that Planck's idea was needed to explain another puzzling behavior of light, called the photoelectric effect. These developments led Louis de Broglie to make an inspired guess: If waves (such as light) can act like particles, then perhaps particles (such as electrons) can act like waves. And, indeed, this proved to be the case. It took a generation of brilliant physicists (including Bohr, Heisenberg, Schrödinger, Born, Dirac, and Pauli) to develop a mathematically consistent and coherent theory that described and made some sense out of wave-particle duality. Their quantum theory has been spectacularly successful. It has been applied to a vast range of phenomena, and hundreds of thousands of its predictions about all sorts of physical systems have been confirmed with astonishing accuracy.

Great theoretical advances in physics typically result in profound unifications of our understanding of nature. Newton's theories gave a unified account of celestial and terrestrial phenomena; Maxwell's equations unified electricity, magnetism, and optics; and the theory of relativity unified space and time. Among the many beautiful things quantum theory has given us is a unification of particles and forces. Faraday saw that forces arise from fields, and Maxwell saw that fields give rise to waves. Thus, when quantum theory showed that waves are particles (and particles waves), a deep unity of nature came into view: The forces by which matter interacts and the particles of which it is composed are both manifestations of a single kind of thing-“quantum fields.”

The puzzle of how the same thing can be both a wave and a particle remains, however. Feynman called it “the only real mystery” in science. And he noted that, while we “can tell how it works,” we “cannot make the mystery go away by ‘explaining' how it works.” Quantum theory has a precise mathematical formalism, one on which everyone agrees and that tells how to calculate right answers to the questions physicists ask. But what really is going on remains obscure-which is why quantum theory has engendered unending debates over the nature of physical reality for the past eighty years.

The problem is this: At first glance, wave-particle duality is not only mysterious but inconsistent in a blatant way. The inconsistency can be understood with a thought experiment. Imagine a burst of light from which a light wave ripples out through an ever-widening sphere in space. As the wave travels, it gets more attenuated, since the energy in it is getting spread over a wider and wider area. (That is why the farther you are from a light bulb, the fainter it appears.) Now, suppose a light-collecting device is set up, a box with a shutter-essentially, a camera. The farther away it is placed from the light burst, the less light it will collect. Suppose the light-collecting box is set up at a distance where it will collect exactly a thousandth of the light emitted in the burst. The inconsistency arises if the original burst contained, say, fifty particles of light. For then it appears that the light-collector must have collected 0.05 particles (a thousandth of fifty), which is impossible, since particles of light are indivisible. A wave, being continuous, can be infinitely attenuated or subdivided, whereas a particle cannot.

Quantum theory resolves this by saying that the light-collector, rather than collecting 0.05 particles, has a 0.05 *probability* of collecting *one* particle. More precisely, the *average* number of particles it will collect, if the same experiment is repeated many times, is 0.05. Wave-particle duality, which gave rise to quantum theory in the first place, forces us to accept that quantum physics is inherently probabilistic. Roughly speaking, in pre-quantum, classical physics, one calculated what actually happens, while in quantum physics one calculates the relative probabilities of various things happening.

This hardly resolves the mystery. The probabilistic nature of quantum theory leads to many strange conclusions. A famous example comes from varying the experiment a little. Suppose an opaque wall with two windows is placed between the light-collector and the initial burst of light. Some of the light wave will crash into the wall, and some will pass through the windows, blending together and impinging on the light-collector. If the light-collector collects a particle of light, one might imagine that the particle had to have come through either one window or the other. The rules of the quantum probability calculus, however, compel the weird conclusion that in some unimaginable way the single particle came through both windows at once. Waves, being spread out, can go through two windows at once, and so the wave-particle duality ends up implying that individual particles can also.

Things get even stranger, and it is clear why some people pine for the good old days when waves were waves and particles were particles. One of those people was Albert Einstein. He detested the idea that a fundamental theory should yield only probabilities. “God does not play dice!” he insisted. In Einstein's view, the need for probabilities simply showed that the theory was incomplete. History supported his claim, for in classical physics the use of probabilities always stemmed from incomplete information. For example, if one says that there is a 60 percent chance of a baseball hitting a glass window, it is only because one doesn't know the ball's direction and speed well enough. If one knew them better (and also knew the wind velocity and all other relevant variables), one could definitely say whether the ball would hit the window. For Einstein, the probabilities in quantum theory meant only that there were as-yet-unknown variables: hidden variables, as they are called. If these were known, then in principle everything could be predicted exactly, as in classical physics.

Many years have gone by, and there is still no hint from any experiment of hidden variables that would eliminate the need for probabilities. In fact, the famed Heisenberg Uncertainty Principle says that probabilities are ineradicable from physics. The thought experiment of the light burst and light-collector showed why: If one and the same entity is to behave as both a wave and a particle, then an understanding in terms of probabilities is absolutely required. (For, again, 0.05 of a

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particle makes no sense, whereas a 0.05 *chance* of a particle does.) The Uncertainty Principle, the bedrock of quantum theory, implies that even if one had all the information there is to be had about a physical system, its future behavior cannot be predicted exactly, only probabilistically.

This last statement, if true, is of tremendous philosophical and theological importance. It would spell the doom of determinism, which for so long had appeared to spell the doom of free will. Classical physics was strictly deterministic, so that (as Laplace famously said) if the state of the physical world were completely specified at one instant, its whole future development would be exactly and uniquely determined. Whether a man lifts his arm or nods his head *now* would (in a world governed by classical physical laws) be an inevitable consequence of the state of the world a billion years ago.

But the death of determinism is not the only deep conclusion that follows from the probabilistic nature of quantum theory. An even deeper conclusion that some have drawn is that materialism, as applied to the human mind, is wrong. Eugene Wigner, a Nobel laureate, argued in a famous essay that philosophical materialism is not "logically consistent with present quantum mechanics." And Sir Rudolf Peierls, another leading physicist, maintained that "the premise that you can describe in terms of physics the whole function of a human being . . . including its knowledge, and its consciousness, is untenable."

These are startling claims. Why should a mere theory of matter imply anything about the mind? The train of logic that leads to this conclusion is rather straightforward, if a bit subtle, and can be grasped without knowing any abstruse mathematics or physics.

It starts with the fact that for *any* physical system, however simple or complex, there is a master equation-called the Schrödinger equation-that describes its behavior. And the crucial point on which everything hinges is that the Schrödinger equation yields only probabilities. (Only in special cases are these exactly 0, or 100 percent.) But this immediately leads to a difficulty: There cannot always remain *just* probabilities; eventually there must be definite outcomes, for probabilities must be the probabilities *of* definite outcomes. To say, for example, there is a 60 percent chance that Jane will pass the French exam is meaningless unless at some point there is going to be a French exam on which Jane will receive a definite grade. Any mere probability must eventually stop being a mere probability and become a certainty or it has no meaning even as a probability. In quantum theory, the point at which this happens, the moment of truth, so to speak, is traditionally called the collapse of the wave function.

The big question is when this occurs. Consider the thought experiment again, where there was a 5 percent chance of the box collecting one particle and a 95 percent chance of it collecting none. When does the definite outcome occur in this case? One can imagine putting a mechanism in the box that registers when a particle of light has been collected by making, say, a red indicator light to go on. The answer would then seem plain: The definite outcome happens when the red light goes on (or fails to do so). But this does *not* really produce a definite outcome, for a simple reason: Any mechanism one puts into the light-collecting box is just itself a physical system and is therefore described by a Schrödinger equation. And that equation *yields only probabilities*. In particular, it would say there is a 5 percent chance that the box collected a particle and that the red indicator light is on, and a 95 percent chance that it did not collect a particle and that the indicator light is off. No definite outcome has occurred. Both possibilities remain in play.

This is a deep dilemma. A probability must eventually get resolved into a definite outcome if it is to have any meaning at all, and yet the equations of quantum theory when applied to any physical system yield only probabilities and not definite outcomes.

Of course, it seems that when a *person* looks at the red light and comes to the knowledge that it is on or off, the probabilities do give way to a definite outcome, for the person knows the truth of the matter and can affirm it with certainty. And this leads to the remarkable conclusion of this long train of logic: As long as only physical structures and mechanisms are involved, however complex, their behavior is described by equations that yield only probabilities-and once a mind is involved that can make a rational judgment of fact, and thus come to knowledge, there is certainty. Therefore, such a mind cannot be just a physical structure or mechanism completely describable by the equations of physics.

Has there been a sleight-of-hand? How did mind suddenly get into the picture? It goes back to probabilities. A probability is a measure of someone's state of knowledge or lack of it. Since quantum theory is probabilistic, it makes essential reference to someone's state of knowledge. That someone is traditionally called the observer. As Peierls explained, “The quantum mechanical description is in terms of knowledge, and knowledge requires *somebody* who knows.”

I have been explaining some of the implications (as Wigner, Peierls, and others saw them) of what is usually called the traditional, Copenhagen, or standard interpretation of quantum theory. The term “Copenhagen interpretation” is unfortunate, since it carries with it the baggage of Niels Bohr's philosophical views, which were at best vague and at worst incoherent. One can accept the essential outlines of the traditional interpretation (first clearly delineated by the great mathematician John von Neumann) without endorsing every opinion of Bohr.

There are many people who do not take seriously the traditional interpretation of quantum theory-precisely because it gives too great an importance to the mind of the human observer. Many arguments have been advanced to show its absurdity, the most famous being the Schrödinger Cat Paradox. In this paradox one imagines that the mechanism in the light-collecting box kills a cat rather than merely making a red light go on. If, as the traditional view has it, there is not a definite outcome until the human observer knows the result, then it would seem that the cat remains in some kind of limbo, not alive or dead, but 95 percent alive and 5 percent dead, until the observer opens the box and looks at the cat-which is absurd. It would mean that our minds create reality or that reality is perhaps only in our minds. Many philosophers attack the traditional interpretation of quantum theory as denying objective reality. Others attack it because they don't like the idea that minds have something special about them not describable by physics.

The traditional interpretation certainly leads to thorny philosophical questions, but many of the common arguments against it are based on a caricature. Most of its seeming absurdities evaporate if it is recognized that what is calculated in quantum theory's wavefunction is not to be identified simply with what is happening, has happened, or will happen but rather with *what someone is in a position to assert* about what is happening, has happened, or will happen. Again, it is about someone's (the observer's) *knowledge*. Before the observer opens the box and looks at the cat, he is not in a position to assert definitely whether the cat is alive or dead; afterward, he is-but the traditional interpretation does *not* imply that the cat is in some weird limbo until the observer looks. On the contrary, when the observer checks the cat's condition, his observation can include all the tests of forensic pathology that would allow him to pin down the time of the cat's death and say, for instance, that it occurred thirty minutes before he opened the box. This is entirely consistent with the traditional interpretation of quantum theory. Another observer who checked the cat at a different time would have a different “moment of truth” (so the wavefunction that expresses *his* state of knowledge would collapse when *he* looked), but he would deduce the same time of death for the cat. There is nothing subjective here about the cat's death or when it occurred.

The traditional interpretation implies that just knowing A, B, and C, and applying the laws of quantum theory, does not always answer (except probabilistically) whether D is true. Finding out definitely about D may require another observation. The supposedly absurd role of the observer is really just a concomitant of the failure of determinism.

The trend of opinion among physicists and philosophers who think about such things is away from the old Copenhagen interpretation, which held the field for four decades. There are, however, only a few coherent alternatives. An increasingly popular one is the many-worlds interpretation, based on Hugh Everett's 1957 paper, which takes the equations of physics as the whole story. If the Schrödinger equation never gives definite and unique outcomes, but leaves all the possibilities in play, then we ought to accept this, rather than invoking mysterious observers with their minds' moments of truth.

So, for example, if the equations assign the number 0.05 to the situation where a particle has been collected and the red light is on, and the number 0.95 to the situation where no particle has been collected and the red light is off, then we ought to say that *both situations are parts of reality* (though one part is in some sense larger than the other by the ratio 0.95 to 0.05). And if an observer looks at the red light, then, since he is just part of the physical system and subject to the same equations, there will be a part of reality (0.05 of it) in which he sees the red light on and another part of reality (0.95 of it) in which he sees the red light off. So physical reality splits up into many versions or branches, and each human observer splits up with it. In some branches a man will see that the light is on, in some he will see that the light is off, in others he will be dead, in yet others he will never have been born. According to the many-worlds interpretation, there are an infinite number of branches of reality in which objects (whether particles, cats, or people) have endlessly ramifying alternative histories, all equally real.

Not surprisingly, the many-worlds interpretation is just as controversial as the old Copenhagen interpretation. In the view of some thinkers, the Copenhagen and many-worlds interpretation both make the same fundamental mistake. The whole idea of wave-particle duality was a wrong turn, they say. Probabilities are needed in quantum theory because in no other way can one make sense of *the same entity* being both a wave and a particle. But there is an alternative, going back to de Broglie, which says they are *not* the same entity. Waves are waves and particles are particles. The wave guides, or “pilots,” the particles and tells them where to go. The particles surf the wave, so to speak. Consequently, there is no contradiction in saying both that a tiny fraction of the wave enters the light collector and that a whole-number of particles enters-or in saying that the wave went through two windows at once and each particle went through just one.

De Broglie's pilot-wave idea was developed much further by David Bohm in the 1950s, but it has only recently attracted a significant following. “Bohmian theory” is not just a different interpretation of quantum theory; it is a different theory. Nevertheless, Bohm and his followers have been able to show that many of the successful predictions of quantum theory can be reproduced in theirs. (It is questionable whether all of them can be.) Bohm's theory can be seen as a realization

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of Einstein's idea of hidden variables, and its advocates see it as a vindication of Einstein's well-known rejection of standard quantum theory. As Einstein would have wanted, Bohmian theory is completely deterministic. Indeed, it is an extremely clever way of turning quantum theory back into a classical and essentially Newtonian theory.

The advocates of this idea believe that it solves all of the quantum riddles and is the only way to preserve philosophical sanity. However, most physicists, though impressed by its cleverness, regard it as highly artificial. In my view, the most serious objection to it is that it undoes one of the great theoretical triumphs in the history of physics: the unification of particles and forces. It gets rid of the mysteriousness of quantum theory by sacrificing much of its beauty.

What, then, are the philosophical and theological implications of quantum theory? The answer depends on which school of thought-Copenhagen, many worlds, or Bohmian-one accepts. Each has its strong points, but each also has features that many experts find implausible or even repugnant.

One can find religious scientists in every camp. Peter E. Hodgson, a well-known nuclear physicist who is Catholic, insists that Bohmian theory is the only metaphysically sound alternative. He is unfazed that it brings back Newtonian determinism and mechanism. Don Page, a well-known theoretical cosmologist who is an evangelical Christian, prefers the many-worlds interpretation. He isn't bothered by the consequence that each of us has an infinite number of alter egos.

My own opinion is that the traditional Copenhagen interpretation of quantum theory still makes the most sense. In two respects it seems quite congenial to the worldview of the biblical religions: It abolishes physical determinism, and it gives a special ontological status to the mind of the human observer. By the same token, it seems quite uncongenial to eastern mysticism. As the physicist Heinz Pagels noted in his book *The Cosmic Code*: “Buddhism, with its emphasis on the view that the mind-world distinction is an illusion, is really closer to classical, Newtonian physics and not to quantum theory [as traditionally interpreted], for which the observer-observed distinction is crucial.”

If anything is clear, it is that quantum theory is as mysterious as ever. Whether the future will bring more-compelling interpretations of, or even modifications to, the mathematics of the theory itself, we cannot know. Still, as Eugene Wigner rightly observed, “It will remain remarkable, in whatever way our future concepts develop, that the very study of the external world led to the conclusion that the content of the consciousness is an ultimate reality.” This conclusion is not popular among those who would reduce the human mind to a mere epiphenomenon of matter. And yet matter itself seems to be telling us that its connection to mind is more subtle than is dreamt of in their philosophy.

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