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Quantum Shmantum

FROM *DISCOVER*

One of the paradoxes of quantum physics is that elementary particles can seemingly exist in more than one state at once. One interpretation of why this is so is known as the "many-worlds" theory: Each of those quantum states represents an entire universe. The maverick physicist David Deutsch adamantly takes this theory to its inevitable conclusion: that at every moment, we all exist in an infinite number of other universes. The journalist Tim Folger catches up to Deutsch—or one version of him, at least.

At three o'clock on a warm summer afternoon, I arrive as scheduled at David Deutsch's home in Oxford, England. Deutsch, one of the world's leading theoretical physicists, a distinguished fellow of the British Computer Society and champion of what must certainly be the strangest scientific worldview ever created, is something of a recluse. He likes to sleep late and warned me not to come too early. Although I'm on time, my knocks on his door go unanswered. The house is dark and quiet. The doorbell doesn't seem to be working. After about 10 minutes a light goes on in an upstairs window, followed by the sound of running water. I knock harder, which at last triggers activity on the other side of the door. I hear feet pounding down stairs; the door opens, and Deutsch asks me to come in.

Piles of precariously stacked books line the route to his office, rising from the floor like stalagmites. A large poster of a brooding Albert Einstein hangs on one wall. Deutsch sits, sipping orange juice. He is slender, with birdlike attentiveness, and for someone who hardly ever leaves his home, surprisingly friendly and open. He looks much younger than 48. If his arguments, which have won over more than a few of his colleagues, turn out to be correct, our meeting is also occurring countless times in innumerable parallel universes, all in perfect accord with the uncanny laws of quantum theory.

Few physicists deny the validity of these laws, although they might not agree with Deutsch's interpretation of them. The laws insist that the fundamental constituents of reality, such as protons, electrons, and other subatomic particles, are not hard and indivisible. They behave like both waves and particles. They can appear out of nothing—a pure void—and disappear again. Physicists have even managed to teleport atoms, to move them from one place to another without passing through any intervening space. On the quantum scale, objects seem blurred and indistinct, as if created by a besotted god. A single particle occupies not just one position but exists here, there, and many places in between. "That quantum theory is outlandish, everyone agrees," says Deutsch. It seems completely in conflict with the world of big physics according to Newton and Einstein.

To grapple with the contradictions, most physicists have chosen an easy way out: They restrict the validity of quantum theory to the subatomic world. But Deutsch argues that the theory's laws must hold at every level of reality. Because everything in the world, including ourselves, is made of these particles, and because quantum theory has proved infallible in every conceivable experiment, the same weird quantum rules must apply to us. We, too, must exist in many states at once, even if we don't realize it. There must be many versions of late-rising David Deutsches, Earth, and the entire universe. All possible events, all conceivable variations on our lives, must exist, says Deutsch. We live not in a single universe, he says, but in a vast and rich "multiverse."

He knows the idea takes some getting used to, especially when one pauses to consider what it means on an everyday level. For starters, it solves once and for all the ancient question of whether we have free will. "The bottom line is that the universe is open," Deutsch says. "In the relevant sense of the word, we have free will."

We also have every possible option we've ever encountered acted out somewhere in some universe by at least one of our other selves. Unlike the traveler facing a fork in the road in Robert Frost's poem "The Road Not

Taken," who is "sorry that I could not travel both/And be one traveler," we take all the roads in our lives. This has some unsettling consequences and could explain why Deutsch is reluctant to venture from his house.

Driving a car, for example, becomes extremely hazardous, because it's almost certain that somewhere in some other universe the driver will accidentally hit and kill a child. So should we never drive? Deutsch thinks it's impossible to control the fate of our other selves in the multiverse. But if we're cautious, other copies of us may decide to be cautious. "There's also the argument that because the child's death will happen in some universes, you ought to take more care when doing even slightly risky things," he says.

Coming from a physicist of lesser stature, such startling views might be dismissed. But Deutsch possesses impeccable credentials. While still in his early thirties he created the theoretical framework for an entirely new discipline called quantum computation. Spurred by those ideas, researchers around the globe are attempting to construct a fundamentally different type of computer that is powerful almost beyond imagining.

Deutsch himself is more interested in convincing physicists that quantum theory has to be taken into consideration in the everyday world than he is in seeing a quantum computer built. Physicists may argue about what the theory means, but fortunately for the rest of us they have no qualms about working with it. By some estimates, 30 percent of the United States' gross national product is said to derive from technologies based on quantum theory. Without the insights provided by quantum mechanics, there would be no cell phones, no CD players, no portable computers. Quantum mechanics is not a branch of physics; it *is* physics.

And yet more than a century after it was first proposed by German scientist Max Planck, physicists who work with the theory every day don't really know quite what to make of it. They fill blackboards with quantum calculations and acknowledge that it is probably the most powerful, accurate, and predictive scientific theory ever developed. But as Deutsch wrote in an article for the *British Journal for the Philosophy of Science:* "Despite the unrivalled empirical success of quantum theory, the very suggestion that it may be literally true as a description of nature is still greeted with cynicism, incomprehension, and even anger."

To understand why the theory presents a conceptual challenge for physicists, consider the following experiment, based on an optical test first performed in 1801 by Thomas Young:

In the experiment, particles of light—photons—stream through a single vertical slit cut into a screen and fall onto a piece of photographic film placed some distance behind the screen. The image that develops on the film isn't surprising—simply a bright, uniform band. But if a second slit is cut into the screen, parallel to the first, the image on the film changes in an unexpected way: In place of a uniformly bright patch, the photons now form a pattern of alternating bright and dark parallel lines on the film. Dark lines appear in areas that were bright when just one slit was open. Somehow, cutting a second slit for the light to shine through prevents the photons from hitting areas on the screen they easily reached when only one slit was open.

Physicists usually explain the pattern by saying that light has a dual nature; it behaves like a wave, although it consists of individual photons. When light waves emerge from the two slits, overlapping wave crests meet at the film to create the bright lines; crests and troughs cancel out to produce the dark lines.

But there's a problem with this explanation: The same pattern of light and dark lines gradually builds up even when photons pass one at a time through the slits, as if each photon had somehow spread out like a wave and gone through both slits simultaneously. That clearly isn't the case, because the distance between the two slits can be hundreds, thousands, or in principle, any number of times greater than the size of a single photon. And if that isn't confusing enough, consider this: If detectors are placed at each slit, they register a photon traveling through only one of the slits, never through both at the same time.

Yet the photons behave as if they had traveled through both slits at once. The same baffling result holds not just for photons but also for particles of matter, such as electrons. Each seems able to exist in many different places at once—but only when no one is looking. As soon as a physicist tries to observe a particle—by placing a detector at each of the two slits, for example—the particle somehow settles down into a single position, as if it knew it was being detected.

Most physicists, when pressed, will usually say that the lesson quantum mechanics has for us is that our concepts of how a particle should behave simply don't match reality. But Deutsch believes that the implications of the theory are clear: If in every case a particle—be it a photon, an electron, or any other denizen of the quantum world—appears to occupy more than one position at a time, then it clearly *does* occupy many positions at once. And thus so do we, and so does everything else in the universe.

But is that an awfully big conclusion to draw from a simple pattern of light and shadow? Deutsch responds by pointing out that a similarly huge assumption—that the universe is expanding—is based on subtle light and shadow observations. Yet hardly any physicist anywhere disputes it.

Under normal circumstances we never encounter the multiple realities of quantum mechanics. We certainly aren't aware of what our other selves are doing. Only in carefully controlled conditions, as in the two-slit experiment, do we get a hint of the existence of what Deutsch calls the multiverse. That experiment offers a rare example of two overlapping realities, in which photons in one universe interfere with those in another. In our universe, we see a photon passing through one slit that seems to interact with another, invisible photon traveling through the second slit. In another universe, the photon that we see is invisible to the physicist in that world, while the one that we can't see is the photon the otherworldly physicist detects. Peculiar? Deutsch believes there is no alternative way of looking at quantum mechanics. "When it comes to a conflict about what a theory of physics says and what we are expecting, then physics has to win."

Deutsch is not the originator of the multiverse concept. That credit goes to Hugh Everett, whose 1957 Princeton doctoral thesis first presented what has come to be called the "many worlds" interpretation of quantum mechanics.

In creating the many worlds view, Everett was trying to solve the problem of why we see only one of the multiple states in which a particle can exist. Some years before Everett's work, physicists had crafted an ad hoc explanation that to this day remains the standard way of coping with quantum phenomena. In the conventional view, the very act of our observation causes all the possible states of a particle to "collapse" abruptly into a single value, which specifies the position, say, or energy of the particle. To understand how this works, imagine that the particle is an e-mail message. When the message is sent, there are multiple possible outcomes: The e-mail could reach its intended destination; any number of people could get it by mistake; or the sender might receive a notice that the message could not be delivered. But when one outcome is observed, all other possibilities with regard to the e-mail delivery collapse into one reality.

To some physicists the notion of collapse is an unsightly addition to quantum mechanics, tacked on to smooth over the uncomfortable fact that the theory mandates multiple states for every particle in existence. And the collapse model creates its own problems: Because it says our observations affect the outcomes of experiments, it assigns a central role to consciousness. "It's an unpleasant thing to bring people into the basic laws of physics," says Steven Weinberg, a Nobel laureate at the University of Texas.

Everett labored to move beyond those laws, arguing that nothing like a quantum collapse ever occurs and that human consciousness does not determine the outcome of experimental results. He said the collapse only seems to happen from our limited perspective. Everett believed that all quantum states are equally real and that if we see only one result of an experiment, other versions of us must see all the remaining possibilities.

Bryce DeWitt, the physicist who coined the term "many worlds" to describe this perplexing idea, remembers his first reaction to Everett's paper. "I was shocked but delighted," he says. By contrast, other physicists greeted Everett's theory with resounding indifference. "The article appeared, and that was the end of it," says DeWitt. "Just total silence."

The cool reception apparently didn't faze Everett. Although he left physics to work on classified projects for the United States government, he remained convinced until his death in 1982 that he was right about quantum mechanics. And if the many worlds theory is true, Deutsch, for one, believes that other copies of Everett might remain alive somewhere in the multiverse.

In 1976, a few years before he vanished from this corner of the multiverse, Everett, at DeWitt's invitation, visited the University of Texas, where Deutsch was then a graduate student. Like DeWitt before him, Deutsch became a convert. "I don't think there are any interpretations of quantum theory other than many worlds," he says. "The others deny reality."

Deutsch argues that physicists who use quantum mechanics in a utilitarian way—and that means most physicists working in the field today—suffer from a loss of nerve. They simply can't accept the strangeness of quantum reality. This is probably the first time in history, he says, that physicists have refused to believe what their reigning theory says about the world. For Deutsch, this is like Galileo refusing to believe that Earth orbits the sun and using the heliocentric model of the solar system only as a convenient way to predict the positions of stars and planets in the sky. Like modern physicists, who speak of photons as being both wave and particle, here and there at once, Galileo could have argued that Earth is both moving and stationary at the same time and ridiculed impertinent graduate students for questioning what that could possibly mean.

"This dilemma of whether you should accept that the world really is the way a theory says it is or whether you should just think of the theory as a manner of speaking, has occurred with every fundamentally new scientific theory right back to Copernicus," says Deutsch.

"I'm not quite sure why physicists should be more ready to believe in planets in distant galaxies than to believe in Everett's other worlds," says DeWitt. "Of course the number of parallel universes is really huge. I like to say that some physicists are comfortable with little huge numbers but not with big huge numbers."

Indeed, most other physicists view the many worlds route as a road best not taken. Steven Weinberg, paraphrasing Winston Churchill's quip about democracy, says: "It's a miserable idea except for all the other ideas." So which road does Weinberg choose? "I don't know," he says. "I think I come out with the pragmatic people who say, 'Oh, the hell with it. I'm too busy.' "

Christopher Fuchs, a research physicist at Lucent Technologies' Bell Labs, believes that quantum mechanics doesn't tell us so much about the world itself as it does about our interaction with the world. "It represents our interface with reality," he says. "I don't think it goes further than that." Fuchs believes that odd properties of quantum mechanics, such as the apparent ability of particles to exist in many places at once, merely reflect our ignorance of the world and are not true features of reality. "When a quantum state collapses, it's not because anything is happening physically, it's simply because this little piece of the world called a person has come across some knowledge, and he updates his knowledge," he says. "So the quantum state that's being changed is just the person's knowledge of the world, it's not something existent in the world in and of itself."

In Fuch's view, quantum mechanics describes a reality that shrinks away from us when we probe it too closely. "There's a certain ticklishness to the world," he says. "It is this extreme sensitivity of quantum systems that keeps us from ever knowing more about them than can be captured with the formal structure of quantum mechanics."

To Deutsch, such arguments are just complex rationalizations for avoiding the most straightforward implications of quantum theory. "It's a tenable point of view to say I don't know what the world is like," he says. "The obvious question then is what is in fact happening in reality? If quantum theory is true, it puts heavy constraints on what the world can be like."

The most serious consequence of refusing to consider the many worlds view is that physicists will never advance to a new, deeper understanding of nature. Deutsch adds: "What one can hope for in the long run is that a new theory will be facilitated by understanding this present theory. Once you understand the existing theory, you have a handle on what you can change in it. Whereas if you don't understand it, if it's just a set of equations, then it's astronomically unlikely that you will happen upon a better theory."

In the meantime, Deutsch is optimistic that the refined application of quantum mechanics principles will produce a tool that could bolster his argument for the existence of parallel universes. Many physicists around the world, including a team at Oxford with whom Deutsch works, are trying to build a quantum computer that would manipulate atoms or photons and exploit the particles' abilities to exist simultaneously in more than one state. Those quantum properties would tremendously increase the speed and capacity of the computer, allowing it to complete tasks beyond the reach of existing machines. In fact, says Deutsch, a quantum computer could in theory perform a calculation requiring more steps than there are atoms in the entire universe.

To do that, the computer would have to be manipulating and storing all that information somewhere. Computation is, after all, a physical process; it uses real resources, matter and energy. But if those resources exceed the amount available in our universe, then the computer would have to be drawing on the resources of other universes. So Deutsch feels that if such a computer is built, the case for many worlds will be compelling.

IT'S ALMOST SEVEN O'CLOCK in the evening. Deutsch has been answering questions for nearly four hours and has not yet had breakfast. He invites me to his conservatory, and we clamber over book stalagmites to a glassed-in porch facing his backyard for steak and orange juice. Deutsch muses about why people have trouble accepting strange new ideas. "I must say I don't understand the whole psychology of why people like some scientific theories and not others," he says.

He pauses briefly while he lights the "barbecue in a box" on which he will grill his breakfast. While the meat sizzles, he answers one last question: What if quantum theory is wrong?

"I'm sure that quantum theory will be proved false one day, because it seems inconceivable that we've stumbled across the final theory of physics. But I would bet my bottom dollar that the new theory will either retain the parallel universe feature of quantum physics, or it will contain something even more weird."