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One Man's Quantum Culture

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Quantum theory is known largely for being unknown—known, in other words, for how it departs from the world of common experience, how it cannot be explained or grasped, how it defies reason and intuition, and how it toys with the laws of classical physics. It is a science of head-scratching. Matter appears in two places at once. Light acts as a wave and a particle (both, and neither). Multiple possibilities superimpose on the same moment. Particles separated by miles seem directly connected. Electrons seem to act differently when they are watched up close.

Quantum Leaps
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For most of us, these bewilderments must be taken nearly as an article of faith, bolstered by the men and women of science who explain the phenomena with broad strokes and clever thought experiments. To refine these illustrations into the actual theory is to point down a path—out of the cave, up the mountain, down the rabbit hole; take your pick—that few can follow. As a consequence, the *fact* that the universe is so mysterious has been more influential in popular culture than any of the particular mysteries that scientists have described. What has been really compelling is the credibility quantum physics lends to the bizarre. Nearly any pseudo-scientific craziness can seem to fall under the field's umbrella by virtue of the gap separating it from common sense.

Each new generation of students grows up immersed in the world of classical physics, with its mostly intuitive, billiard-ball causality; that is the everyday vantage from which we approach the alien world of quantum physics, which has for this reason never lost its air of radicalism. But there was a time when little of today's credibility attended that edginess, and when talk of the field, whether vague or precise, was the stuff of rumor and outrage, even among the minds who understood it best. "Princeton is a madhouse," J. Robert Oppenheimer wrote his brother in 1935, "its solipsistic luminaries shining in separate & helpless desolation. Einstein is completely cuckoo."

Quantum Leaps, by the physicist and science writer Jeremy Bernstein, looks at the daring progress of this subject since its fitful beginnings in chalk-dusted gossip. Quantum theory has always been, at best, a twilit field, and Bernstein chronicles those who found the darkness irresistible. Bernstein hasn't set out to guide readers through this tiny dimension of oddities so much as to show the circles of thinkers in which that dimension was discovered, and out of which it radiated into public consciousness. His chapters do not offer linear stories; they wander through personalities, moments, and experiments of importance, chatting in a wistful, memoiristic tone. Scientific explanations in *Quantum Leaps* mostly serve to aid this grander story—to sketch a background for the disputes and discoveries that excited the book's cast of geniuses.

Where did it all begin? Circa 1900, Max Planck theorized that energy was made up of discrete units, or "quanta." This was an idea Einstein later applied to light, arguing that it travels in what we now call photons—the smallest units into which light divides. (Hence the latest James Bond film, *Quantum of Solace*, uses the still-hip term to describe the tiniest portion of solace possible—though solace in the form of champagne, fast cars, and fetching European women would in fact involve many quanta. What other new words from the early 1900s can you think of that still sound Bond-worthily modish today?)

The word "quantum" derives from the Latin for "how much," an etymology that suggests the very challenge quantum physics directs toward classical physics—at what size does it hold true? One paradox of quantum physics is that our exploration of ever-smaller particles has made our world seem not larger but somehow smaller, since its laws—or our perception of them—are confined to a human scale. We are creatures of the macro universe, and as we sharpened our view of the atomic scale, we dizzied our sense of time, space, and reason.

Einstein's theory of special relativity drastically changed our understanding of physics, too, but at least this change left us with reason intact, offering a new and better account of the universe's architecture. Things remained predictable and consistent. Quantum physics has been more unsettling. Its revelations show just how little we can predict, and how few of our intuitions make sense when we consider how quanta behave.

One well-known example of this counterintuitiveness is the uncertainty principle developed by Werner Heisenberg in the 1920s, which tells us that we can't know a particle's momentum and position at the same time. The more certain we can be about one part, the less certain we can be about the other. Heisenberg's principle rose out of the discovery that particles, in some cases, act like waves. As a particle's wavelength gets shorter, we can be more sure of where the particle is but less sure about its momentum. With longer wavelengths, it's the other way around. Something is always uncertain.

Scientists spend their careers trying to become certain about things, so it's understandable that some would be dissatisfied with all this subatomic caprice. In 1935, Einstein, Boris Podolsky, and Nathan Rosen derived a paradox (the EPR paradox) from quantum theory to suggest something was wrong, or at least missing, from its view of things. The paradox starts with the discovery that if a pair of particles, an electron and a positron, splits up, they will spin in opposite directions (one "up," the other "down"), even if they get miles apart. This is called "entanglement." If we know that one particle is spinning up, we can be sure that the other particle, wherever it might be, is spinning down. Somehow they are connected, as though the distance of space were arbitrary—perhaps illusory. What's jaw-dropping is that the math, followed to its conclusions, tells us that each particle spins both up *and* down until it is observed. In other words, until someone checks, two different possibilities exist at the same time.

Erwin Schrödinger famously enlivened this paradox by making it a life-or-death scenario (really, a life-*and*-death scenario): He imagined a radioactive solution that had an even chance of decaying—or breaking down and releasing energy—within an hour. Then he imagined a machine that would release poison if it detected the decay. What if we put a cat in a box with the machine and the solution, Schrödinger asked, and waited an hour? The cat's life would depend on whether the solution decayed, since any decay would trigger the poison. Quantum mechanics, said Schrödinger, tells us that the solution has both decayed and not decayed until we check, which means that the poor cat is both dead and alive until we look in the box. (Bernstein tells us he once had tea with Schrödinger; one thing he learned during their visit is that Schrödinger was not fond of cats.)

The EPR paradox was meant to show that quantum theory contradicts itself: that it suggests freakish ideas no reasonable person would accept. Its legacy as an illustration of quantum theory, rather than as a refutation of it, reflects a major transition: reason buckled, not the theory.

The strangest illustration of paradox in quantum physics may be the double-slit experiment, which is rooted in Thomas Young's work with light in around 1801. In 1974, scientists carried out a version of the experiment with electrons, and that is the version we think of today. For a hopelessly simple sketch—akin to explaining that cubism involves cubes—imagine that two walls are facing each other, and that the first wall has a couple slits. When scientists fired electrons at those slits, the ones that got through struck the second wall. The patterns on the second wall looked like waves had rippled through the slits and collided with each other in a wave interference pattern, like water would. Scientists figured that shooting one electron at a time would make it impossible for any of the waves to interfere with each other. A wave won't make an interference pattern if there are no other waves around to interfere with it. But over time, the electrons landed, one by one, as though they were bumping into other waves. They left the same interference pattern. But why?

The quantum mechanical explanation is that as an electron travels, all different possibilities exist at once—it passes through the right slit *and* the left slit *and* it misses both slits, and so on. With all those possibilities happening at once, the electron wave *bumps into another version of itself.* Then the different possibilities collapse back into just the one electron, now traveling as though another electron had interfered with it. Yet this is garden-variety strangeness compared to the next discovery: When people used instruments to check which slit each electron passed through, the electrons stopped making a wave pattern. They just landed in roughly two clumps, one for each slit, the way marbles would (in other words, like electrons traveling as particles). As with Schrödinger's cat, watching electrons seems to make them choose a single possibility.

The notion that to see is to influence, that observation changes the world of the observer, can make a few palms sweaty. The eighteenth-century philosopher George Berkeley was one of many to suggest that all truth could be reduced to perceptions, since it was meaningless to talk about a world that existed beyond them—we never experience *things*, he reminded us, only our perceptions of them. Out walking one day, the great critic Samuel Johnson famously responded to Berkeley's philosophy by kicking a large stone and shouting, "I refute it *thus.*" Johnson didn't mean this as a subtle argument. But he did demonstrate that off paper and out of the armchair, these notions are untenable in actual life, regardless of whether they are true.

One sweaty-palmed thinker was Vladimir Lenin. His *Materialism and Empirio-Criticism* (1908) railed against Ernst Mach, an Austrian whose work in physics Einstein considered a precursor to his own theory of relativity. Mach's philosophy of science, meanwhile, was a precursor to the school of logical positivism, which held that no fact is meaningful unless it can be verified in terms of sense impressions. Mach worried that scientific laws and theories turn reality into a set of abstractions that can never contain reality itself; science describes our perception of an experiment, not the truths that underlie its outcome. Something like an anti-atomist, Mach liked to say "show me" when scientists insisted that atoms were real. He didn't object to the raw science so much as to the comfort others had that they were drawing meaningful conclusions by way of abstractions.

To place truth in the hands of observation does not play well with the Marxist notion (dialectical materialism) that matter is what matters, and Lenin struck some early blows in the long "ideological struggle for the soul of the quantum theory," as Bernstein puts it. A 1952 letter from Belgian physicist Léon Rosenfeld to Frédéric Joliot-Curie, the Nobel laureate and husband of Marie Curie's daughter, shows how far this "ideological struggle" penetrated the seemingly innocent sphere of equations. In the letter, Rosenfeld complained of his disagreements with a group of brilliant young physicists: "I have taken pains to do an explicit Marxist analysis.... As the only response, [French astrophysicist Évry] Schatzman sent me a polemical writing full of incorrect physics and quotations from Stalin." Around the same time, Bernstein leafed through newly translated Russian texts on quantum physics and found, on every few pages, some commentary that related the subject matter to dialectical materialism—friendly political asides that Bernstein charmingly calls "little commercial messages from the 'sponsor.'"

As Bernstein points out, the "good clean fun" of Lenin-era dissent evaporated during the Great Purge in the Soviet Union and the Nazi invasions that soon followed. Not every scientist was so lucky to be caught up in, rather than destroyed by, the times. Matvei Petrovich Bronstein, "a physicist and astrophysicist of great promise," was one such scholar, added in 1938 to Stalin's long execution list and killed soon after. Occasionally, however, Stalin seems to have thought science ought to progress—if only for the sake of nuclear weaponry—without too much intervention. When the chief of the Soviet secret police warned Stalin that some of the scientists in the nuclear weapons program weren't on message, Stalin is said to have replied, "Leave my physicists alone. We can always shoot them later."

Not surprisingly, the fourteenth (current) Dalai Lama was far more congenial to the notion that observation might affect the universe. In fact, both he and his predecessor grew up with a strong interest in science, and the current Dalai Lama's *The Universe in a Single Atom* (2005) deals eloquently with its relation to Buddhism. The Dalai Lama was well prepared to write such a book. In 1979 he invited two eminent philosopher-physicists, David Bohm and Carl Friedrich von Weizsäcker, to tutor him about quantum physics. Bohm was a star quantum physicist whose doctoral work had been classified for use on the Manhattan Project. Of particular interest, the Dalai Lama wrote, were Bohm's thoughts about the incorporation of consciousness into a physics "in which both matter and consciousness manifest according to the same principles."

When the Dalai Lama and a group of Tibetan monks visited a major research laboratory near Geneva in 1983, Bernstein's friend John Bell (he of Bell's Theorem, a keystone in quantum theory) gave a talk on quantum physics. Might the Big Bang, Bell asked the Dalai Lama—or perhaps a Bang-and-Crunch cycle of collapse and explosion—be reconciled with the Buddhist concept of a "constantly recycled" universe? *Maybe*, was the Dalai Lama's reply (in essence), though Bell noted that there hasn't been a great deal of pressure for such a reconciliation. While the universe may have hard and fast laws, our understanding of them shifts, expands, and sometimes collapses too often for the religious culture of Buddhism, which steadies faith on eternal truths. Quantum theory seems to have been easier to reconcile with Buddhist thought because both suggest, albeit in different ways, that our experience of space and matter is illusory.

Of course, not everyone is quite so profound about Buddhism as the Dalai Lama, nor about quantum physics, nor about their connection. Buddhist ideas have also served to vaguely accredit quantum theory-inspired mumbo jumbo, just as the word "quantum" suspends enough disbelief for the wildest embellishments of science fiction. And with the wispy outlines of a "quantum Buddhist" view, some will try and sell you bridges to the next world.

One of the more popular recent treatments of quantum physics is *What the Bleep Do We Know!?* (2004), a documentary-style film that scrambles science, fiction, and philosophy into a kind of self-help mysticism. Respected doctors and physicists stepped in to explain much of the science in the film, but later they found that their ideas had been melted down and recast into New Age spiritual platitudes. They might not have participated had they known ahead of time that the film's directors were disciples of Ramtha, an enlightened spirit who (according to the woman from Washington state who channels him) led ancient battles against the people of Atlantis.

Bernstein has a nice breathalyzer test for pseudo-science intoxication. As an example, he excerpts the writing of Gary Zukav, a bestselling, Oprah-approved author who relates the cycles of subatomic particles to the soul's cycle of rebirth (glibly and foggily). "I have a test," remarks Bernstein, "for phrases like 'which is part of the world of form, which is part of emptiness, which is form.' I negate the propositions: 'which is not part of the world of form, which is not emptiness, which is not form.'

If I cannot attach more sense to one as opposed to the other, I go on to something else."

Bernstein's quantum retrospective is also a personal recollection. He was a student at Princeton University during the late 1950s when it was a modern Athens of math and physics, later joined *The New Yorker* as a staff writer, and is now a veteran author and college professor. His memories are practically one long reel of intellectual-superstar cameos. Newton stood on the shoulders of giants; Bernstein rubbed elbows with them. And plenty of the big names he hasn't met personally were known to his friends and colleagues. By the last third of the book, when Bernstein passingly mentions, "When I was in high school I spent some time with Duke Ellington," it's simply par for course. This is helpful: It can be easy to think of physicists squinting in their laboratories, novelists scribbling by their bedroom windows, painters smoking above the oils in their studios, and so on. Bernstein's litany of encounters demonstrates that the legendary figures of these different disciplines were real people milling through the same places here on Earth, and that their various projects likewise shared contexts and preoccupations. Scientific work, Bernstein's approach reminds us, is cradled in the broader lives of scientists.

Still, Bernstein's scattershot approach sometimes obscures that point, and any other he might be seeking to make. In just the first few pages, we learn that while Bernstein was at Princeton, W. H. Auden happened to sit next to him on a train ride. A little while later Auden, along with Oppenheimer, the theologian Reinhold Niebuhr, the historian Sir Llewelyn Woodward, and two others joined Bernstein for lunch at Princeton. But that brainy lunch itself is just a minor scene in Bernstein's first chapter. More important to Bernstein is his detective work investigating references in Auden's poetry to physics, and especially to Ernest Barnes, who was both a scientist and an Anglican bishop. In his 1937 poem "Letter to Lord Byron," Auden mentions "cheery…English bishops on the Quantum Theory," and elsewhere name-checks "Bishop Barnes" and another famous physicist, James Jeans. Bernstein follows the breadcrumbs of Barnes's work to find out why Auden might have noticed it. Along the way we saunter through a jumble of snippets and anecdotes—some fascinating, some trivial, yet none with any clear relevance to the progress of the chapter beyond how it leads the narrator, finally, back to an idle curiosity about Auden that has long since muddled into a brandy-breathed fireside reminiscence.

Unfortunately, this sort of disarray characterizes too much of *Quantum Leaps*. A little digressive enthusiasm can liberate a book like this to snatch up tidbits purely for the sake of enjoyment—welcome padding for its point-making. But the names and adventures of quantum physics simply need too much explanation for a book that is laid out like a dinner of tapas. Elsewhere in the book, for example, Bernstein abruptly tells us "I went through a chess-playing phase." In fact, Bernstein once joined about forty players in a simultaneous match against Samuel Reshevsky, one of the great American grandmasters, in Rochester, New York. There, Bernstein spotted "a man with a very distinctive angular face" who turned out to be Marcel Duchamp. Art enthusiasts might know that Duchamp dropped art to study chess during the last few decades of his life. This is neat. But what does it have to do with quantum physics? Well, Bernstein explains, if he had recognized Duchamp, he *would* have asked him about how Einstein and Henri Poincaré influenced his cubist paintings, which reminds him, come to think of it, that the novelist Lawrence Durrell *did* confirm a connection between his work and quantum physics. Neither of these links is considered in any depth.

Many of the quantum physics references that Bernstein registers in popular and literary culture start with this sort of nearly spontaneous digression, peak with an insightful catalogue of related examples, then fizzle out by tediously debunking any poorly understood concepts in the work at hand. While those exercises are occasionally interesting, some of the debunkees, like Gary Zukav, hardly seem worth the effort. For more serious figures like Tom Stoppard and Michel Houellebecq, Bernstein rests on the little serendipities that introduced them to quantum physics; one wishes that he would instead try to explain what their references to his discipline might tell us about the way art and culture absorb cutting-edge science.

One criticism of quantum theory has been that it describes quantum phenomena without offering any deep explanation of its observations. The same might be said of the way *Quantum Leaps* approaches its subject. It travels through different times and places at once. Separate ideas are somehow entangled, but the reader is unsure why. And while the observations are individually revealing, the book fails to show how they cohere. You might call it the Bernstein Uncertainty Principle: the more we understand a particular concept in quantum theory, the less we understand its relation to the book.

In fairness, Bernstein has not set out to provide a comprehensive account of quantum physics in this slim volume. Instead, he has rifled through his subject in a warm and deeply personal spirit of eclecticism. To discuss difficult science with a sense of excitement, humanity, and wit is a welcome alternative to another creaky textbook or a brow-furrowing treatise, especially for the lay reader. The trouble isn't that Bernstein has refused to labor over a primer; it's that he has failed to tie together the many wonders upon which his whimsy has alighted. While science, history, and personal memories can form an elegant whole that is more satisfying than any single approach could offer, *Quantum Leaps* undermines each of these approaches by idly mixing them—it dilutes each perspective with the others.

The great American physicist Richard Feynman once remarked, "We choose to examine a phenomenon which is impossible, *absolutely* impossible, to explain in any classical way, and which has in it the heart of quantum mechanics. In reality it contains the *only* mystery." *Quantum Leaps* is valuable for its appreciation of just how mystifying quantum physics has been for its researchers. Bernstein's discussions combine the patience of a teacher with the awe of a student, and it is this well-studied passion, when the book works, that helps render his subject vividly before the reader. His stories will be worth telling for at least as long as the atom is mysterious—and that may last the term of our species.

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