The Mind and the Brain: Neuroplasticity and the Power of Mental Force - Jeffrey M. Schwartz, Sharon Begley (2003)

Chapter 8. THE QUANTUM BRAIN

Anyone who is not shocked by quantum theory has not understood it.

—*Niels Bohr*

I am now convinced that theoretical physics is actual philosophy.

—*Max Born*, My Life and My Views

Science no longer is in the position of observer of nature, but rather recognizes itself as part of the interplay between man and nature. The scientific method…changes and transforms its object: the procedure can no longer keep its distance from the object.

—*Werner Heisenberg, 1958*

In the autumn of 1997, I was laboring to rework my second book. One of the joys of my life, *A Return to Innocence* is based on a series of letters I exchanged with a sixteen-year-old named Patrick on how to use mindfulness to cope with the raging changes in body, mind, and brain that accompany the transition from adolescence to adulthood. As respite, I drove up to Santa Cruz that October to visit the forty acres of redwood forest I had been fortunate enough to acquire in the nearby town of Boulder Creek several years before. During the drive north, I tried to work through what I considered a key reason for the disagreement between the materialist-reductionist view I abhorred and the view of those who, in the philosopher David Chalmers's words, "take consciousness seriously." That disagreement, I was more and more convinced, largely turned on the differing perspectives the two sides took on a deceptively simple question: what counts as primary, or irreducible, data? To those who take consciousness seriously, it is not only permissible but even vital to count subjective phenomena—phenomena such as what consciousness feels like from the inside. Such subjective phenomena have not been reduced to phenomena of a different type. The feeling of pain, the feeling of red (as discussed in Chapter 1), the subjective experience of sadness—none has in any way been convincingly explained away as the mere by-product of the firings of neurons and the release of neurotransmitters. In 1997, no less than now, it was beginning to look as if maybe they never would be. From my perspective, they never could.

In a book published the year before, *The Conscious Mind: In Search of a Fundamental Theory*, Chalmers had advanced a thesis consistent with this view. He argued that contemporary neuroscience doesn't even begin to explain how subjective experience arises from the electrochemical chatter of brain neurons. Such reductionist explanations fall so far short of the goal, Chalmers maintained, that the whole enterprise of seeking an explanation of consciousness solely in the stuff of the brain was fatally flawed, and therefore doomed from the start. Instead, Chalmers suggested that conscious experience is inherently and forever irreducible to anything more "basic"—including anything material. Perhaps it should instead be understood in an entirely new way, he said: perhaps conscious experience is an irreducible entity, like space, or time, or mass. No member of that triad can be explained, much less understood, as a manifestation of either of the other two. Perhaps conscious experience, too, is such a fundamental.

Yet Chalmers also believed in *causal closure*, the idea that only the physical can act on the physical: if a phenomenon is nonphysical (like consciousness), then it is powerless to affect anything made out of the tissues, molecules, and atoms of the physical (like a brain). Chalmers, good epiphenomenalist that he was, accepted that consciousness is real and nonreducible but believed that it is caused by the brain and cannot act back on anything material. (Within a couple of years, as we saw in Chapter 1, Chalmers had modified this last part.) I, of course, disagreed vehemently with the idea of causal closure. My OCD data, not to mention twenty-five years of practice in mindfulness meditation, had persuaded me that the nonphysical entity we call the mind has the power to change the brain. Just before I left L.A., as I was struggling to find a way to explain my notions of mindfulness in *A Return to Innocence*, I hit on the idea of *mental force*. It was little more than a literary device, really, a way to convey the notion that through intense effort we can resist our baser appetites. And although I believed in the concept in a spiritual sense, I wasn't yet thinking about whether such a mental force might have a physical reality.

That Chalmers did not subscribe to diehard materialism—and was quite a nice guy—had led to a budding philosophical friendship over the past year. A few weeks before, I had sent the first e-mail of my life—to Chalmers. "I'm really just checking to see if there is any consciousness on the other end of this," I typed, full of doubts about this newfangled toy. Almost immediately Dave replied, "Consider it affirmed: consciousness exists." So during my trip to Santa Cruz I arranged to drop in, with no firmer plans than to shoot the breeze and catch up with Dave. Which is how I came to be sitting with him on his porch that Sunday afternoon, overlooking Santa Cruz, and discussing all things mind-brain. Over a couple of beers, I began lamenting the terrible social consequences of materialism and my view that the less-than-laudable moral condition of America in general and Santa Cruz in particular (I was grumpy from overwork and have never been particularly enamored of the moral condition of Santa Cruz in any event) could be laid at the feet of nearly three centuries of materialist ascendancy. The reigning belief that the thoughts we think and the choices we make reflect the deterministic workings of neurons and, ultimately, subatomic particles seemed to me to have subverted mankind's sense of morality. The view that people are mere machines and that the mind is just another (not particularly special) manifestation of a clockwork physical universe had infiltrated all our thinking, whether or not someone knew a synapse from an axon. Do you know what the most addressable cause of all this moral decrepitude is?, I asked Dave. Materialism! Not the materialism of Rodeo Drive, SUVs, and second homes in Telluride, but materialism as a worldview, a view that holds that the physical is all that exists, and that transcendent human mental experiences and emotions, no matter what grandeur they seem—from within—to possess, are in reality nothing but the expressions of electrical pulses zipping along neurons. Chalmers wouldn't be the first (or the last) to express incredulity that I was blaming the moral morass of the late twentieth century on a school of philosophy that most people had never heard of. Still, there was a hint of sympathy in Chalmers's voice as he asked, "Do you really believe that?"

I did. Chalmers and I then tossed around the names of scholars who might be positing tenable, scientifically based alternatives to materialism. One was David Hodgson. Like Chalmers an Aussie, and a justice on the Australian Supreme Court, he had written *The Mind Matters: Consciousness and Choice in a Quantum World*, published in 1991. Although it may seem odd for a jurist to focus on something as abstruse as materialism and consciousness, materialism clearly poses a bit of a problem for a central tenet of the justice system—namely, that people exert free will in their actions, including their criminal actions. If actions are merely the inevitable consequences of hard-wired brain circuitry—or, pushing the chain of causation back a step, of the genes we inherit from our parents—then the concept of genuine moral culpability becomes untenable. The second researcher whose work suggested an alternative to materialist reductionism, said Chalmers, was a physicist. His name was Henry Pierce Stapp.

When I returned to Los Angeles, I got hold of a copy of Hodgson's book, an imposing volume with a very long section on quantum physics smack in the middle. In a key passage on free will, Hodgson mentioned this same Stapp. A quick search on Amazon.com turned up a collection of Stapp's papers, which I borrowed from the UCLA physics library. After spending a night that stretched into dawn with the collection, I purchased Stapp's 1993 book *Mind, Matter and Quantum Mechanics* that February. The physics of mind-brain relations expounded in his book, I was startled to see, echoes William James's theories, especially James's belief in the reality of will and the efficacy of mental effort. Although hugely influential in the late nineteenth and early twentieth centuries, James's ideas on the power of mind and the existence of free will fell into disrepute with the rise of behaviorism. Why? Well, who can nail down exactly what forces conspire to nourish a radically new scientific proposal or smother it at birth? James himself despaired of the possibility of scientifically demonstrating the efficacy of will. "The utmost that a believer in free-will can ever do will be to show that the deterministic arguments are not coercive," he wrote. He knew that his theories of psychology—in particular his idea that "the feeling of effort" is an "active element which…contributes energy" to bodily action—failed to mesh with classical physics. In contrast, because the behaviorists' theories rested on the classical, deterministic physics of the late nineteenth and early twentieth centuries, they easily trumped James's. The behaviorist paradigm of John Watson held out the promise of a science of psychology in which researchers would discover the rules that govern why humans act, think, and emote as they do, much as they discovered the rules of electricity or hydrology. Behaviorism denies the reality of thoughts and emotions—indeed, of any sort of inner life. Instead of being afraid of something, it claims, we exhibit "a conditioned fear response" instead of loving someone, we show "conditioned love responses."

Stapp suspected that James's theories on mind and brain had been ignored largely because the physics of James's time—the classical, deterministic physics of Newton—not only failed to support his argument but even undermined it, casting it as so much mysticism. For James's ideas to gain traction, then, they had to await not developments in neuroscience or psychology, but a revolution in physics. For as James himself realized, what he was saying about mind in general and will in particular—namely, that "the brain is an instrument of possibilities, not certainties," and that "consciousness…will, if endowed with causal efficacy, reinforce the favorable possibilities and repress the unfavorable or indifferent ones"—directly contradicted the materialist perspective of the late nineteenth century.

In fact, James's perspective on mind and brain is thoroughly modern, Stapp had observed in his 1993 book. James's theories, Stapp argued, are actually more modern than those of the psychologists and philosophers who dominated the field in the decades after James's death in 1910. Indeed, the consistency between James's perspective on attention and will on one hand and the orthodox interpretation of quantum mechanics on the other was almost eerie. It was as if a ghost from psychology past were whispering into the ear of physics present. For once we recognize that classical Newtonian physics does not accurately describe the world and replace it with the quantum physics that does, it emerges naturally and inevitably that the mind has the power to act back on the brain just as James suggested. That makes the notion that mind is strictly determined by the movements of atoms and electrons seem as dated as Newton's powdered wig.

Classical physics held that the reality of the physical world is constituted of infinitesimal particles in a sea of space. Causation, in this scheme, reflects, at bottom, one particle's acting on its immediate neighbor, which in turn acts on its neighbor, until—well, until something happens. Wholly deterministic natural laws govern the behavior of matter. Furthermore, reality consists of material objects forever separated, by the chasm of Cartesian dualism, from the immaterial mind. This mechanistic view—stimulus in, behavior out—evolved into today's neurobiological model of how the mind works: neurotransmitter in, behavior, thought, or emotion out.

But physics in the years since James had undergone a revolution. The development of quantum physics, in the opening decades of the twentieth century, gave James's conclusions about the relationship between attention and will a grounding in physical science that they lacked during his lifetime. Although classical physics had failed to validate—had even undermined—James's theories, it had not had the last word. The very origin of the mind-brain problem lies in a physics that has been outdated for almost a century. Although biologists, as well as many philosophers, cite "the ordinary laws of physics and chemistry" as an explanation for all of the events we gather under the tent labeled "mind," the laws to which they refer "are a matter of the past," as the Nobel physicist Eugene Wigner wrote way back in 1969. "[They] were replaced, quite some time ago, by new laws"—the laws of quantum mechanics.

It has been a century since the German physicist Max Planck fired the opening shot in what would become the quantum revolution. On October 19, 1900, he submitted to the Berlin Physical Society a proposal that electromagnetic radiation (visible light, infrared radiation, ultraviolet radiation, and the rest of the electromagnetic spectrum) exists as tiny, indivisible packets of energy rather than as a continuous stream. He later christened these packets *quanta*. Planck, a new professor at the University of Berlin, had no false modesty about the significance of his new radiation formula: he told his son, Erwin, during a walk that day, "Today I have made a discovery as important as that of Newton." In a lecture to the German Physical Society on December 14, he made his proposal public. Planck viewed his quanta as mere mathematical devices, something he invoked in "an act of desperation" to explain why heated, glowing objects emit the frequencies of energy that they do (an exasperating puzzle known as the *black-body radiation* problem). He did not seriously entertain the possibility that they corresponded to physical entities. It was just that if you treated light and other electromagnetic energy as traveling in quanta, the equations all came out right. But "nobody, including himself, realized that he was opening the door to a completely new theoretical description of nature," said Anton Zeilinger, one of today's leading quantum experimentalists, on the one hundredth anniversary of Planck's talk.

The notion that electromagnetic energy exists as discrete packets of energy rather than a continuous stream became the foundation on which physicists erected what is inarguably the most successful (and strangest) theory in the history of science. The laws of quantum physics not only replicate all the successes of the classical theory they supplanted (that is, a quantum calculation produces an answer at least as accurate as a classical one in problems ranging from the fall of an apple to the flight of a spaceship). They also succeed where the laws of classical physics fail. It is quantum physics, not classical physics, that explains the burning of stars, accounts for the structure of elementary particles, predicts the order of elements in the periodic table, and describes the physics of the newborn universe. Although devised to explain atomic and electromagnetic phenomena, quantum physics has "yielded a deep understanding of chemistry and the solid state," noted the physicist Daniel Greenberger, a leading quantum theorist: quantum physics spawned quantum technologies, including transistors, lasers, semiconductors, light-emitting diodes, scans, PET scans, and MRI machines. "[T]he extent of the success of quantum theory," concluded Greenberger, "comes rather as an undeserved gift from the gods."

Yet gifts from gods, no less than gifts from crafty Greeks, can conceal unwelcome surprises. For quantum physics, in addition to predicting and explaining phenomena that range over fifteen orders of magnitude in energy, has done something else: it has triggered a radical upheaval in our understanding of the world. In place of the tidy cause-and-effect universe of classical physics, quantum physics describes a world of uncertainties, or indeterminism: of limits to our knowledge. It describes a world that often seems to have parted company with common sense, a world at odds with some of our strongest intuitive notions about how things work. In the quantum world, subatomic particles have no definite position until they are measured: the electron orbiting the nucleus of an atom is not the pointlike particle we usually imagine but instead a cloud swathing the nucleus. In the quantum world, a beam of light can behave as a wave or a barrage of particles, depending on how you observe it. Quantities such as the location, momentum, and other characteristics of particles can be described only by probabilities; nothing is certain. "It is often stated that of all the theories proposed in this century, the silliest is quantum theory," the physicist Michio Kaku wrote in his 1995 book *Hyperspace*. "In fact, some say that the only thing that quantum theory has going for it is that it is unquestionably correct."

Correct it may be, but at its core quantum physics departs from classical physics in a very discomfiting way. Integral to quantum physics is the fundamental role played by the observer in choosing which of a plenitude of possible realities will leave the realm of the possible and become actual. For at its core, quantum physics challenges the ontology that permeated the scientific enterprise for centuries, the premise that a real world—independent of human choice and interference—is out there, uninfluenced by our observation of it. Quantum physics makes the seemingly preposterous claim (actually, more than claim, since it has been upheld in countless experiments) that there is no "is" until an observer makes an observation. Quantum phenomena seem to be called into existence by the very questions we ask nature, existing until then in an undefined fuzzy state. This feature of the quantum world led the American physicist John Archibald Wheeler to say that the world comes into being through our knowledge of it—or, as Wheeler put it, we get "its from bits" (bits of knowledge). The Danish physicist Niels Bohr captured the counterintuitive world that physicists were now playing in when he told a colleague, "We all agreed that your theory is crazy. The question which divides us is whether it is crazy enough to have a chance of being correct."

The role of observation in quantum physics cannot be emphasized too strongly. In classical physics, observed systems have an existence independent of the mind that observes and probes them. In quantum physics, however, only through an act of observation does a physical quantity come to have an actual value. Many are the experiments that physicists have dreamed up to reveal the depths of quantum weirdness. I'll follow the lead of the late physicist Richard Feynman, who contributed as much as any scientist after the founders to the development of quantum mechanics. Feynman thought that "the only mystery" of quantum physics resides in a contemporary version of an experiment first performed in 1801. It is called the *double-slit experiment*, and Feynman found it so revealing of the quantum enigmas that he described it as having in it "the heart of quantum mechanics." (I am using the terms *quantum physics, quantum mechanics*, and *quantum theory* interchangeably.) In his book *The Character of Physical Law*, Feynman declared, "Any other situation in quantum mechanics, it turns out, can always be explained by saying, 'You remember the case of the experiment with the two holes? It's the same thing.'"

In 1801, the English polymath Thomas Young rigged up the test that has been known forever after as the two-slit experiment. At the time, physicists were locked in debate over whether light consisted of particles (minuscule corpuscles of energy) or waves (regular undulations of a medium, like water waves in a pond). In an attempt to settle the question, Young made two closely spaced vertical slits in a black curtain. He allowed monochromatic light to strike the curtain, passing through the slits and hitting a screen on the opposite wall. Now if we were to do a comparable experiment with something we know to be corpuscular rather than wavelike—marbles, say—there is no doubt about the outcome. Most marbles we fired at, for instance, a fence missing two slats would hit the fence and drop on this side. But a few marbles would pass through the gaps and, if we had coated the marbles with fresh white paint, leave two bright blotches on the wall beyond, corresponding to the positions of the two openings.

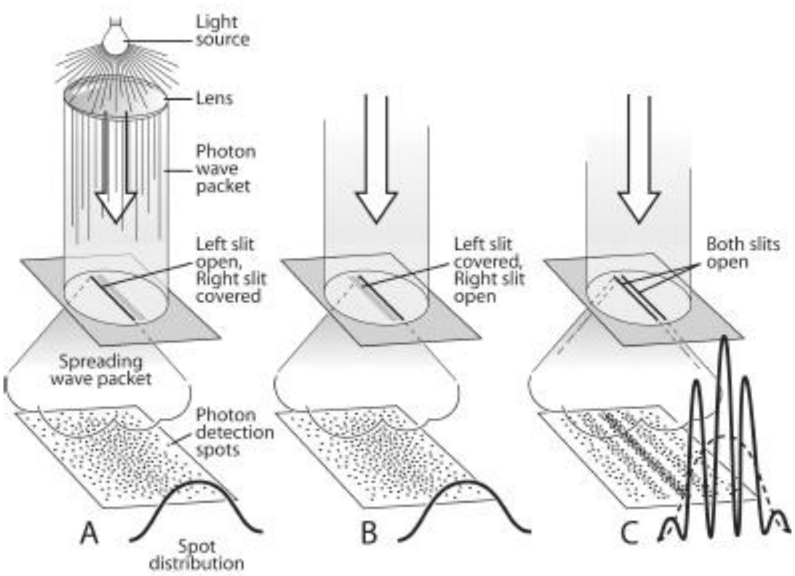

Figure 7: The Double-Slit Experiment. Monochromatic light passes through a two-slit grating. In Experiment A, only one narrow slit is open.The narrowness of the slit, coupled with the quantum Uncertainty Principle, causes the beam that passes through the slit to spread out and cover a wide area of the photographic plate. But each photon is observed to land in a tiny spot. The bell curve shows the distribution of spots, or photons. In B,

only the right slit is open, and again the beam is spread out over a wide area. In C, both slits are open, but the result is not the sum of the single-slit results (dotted curve). Instead, the photons are observed in narrow bands that resemble the interference pattern formed when water waves pass through two openings in a sea wall: as semicircular waves from the two openings ripple outward, they combine where crest meets crest (in the photon experiment, the bands where many photons are found) and cancel when crest meets trough (where photons are scarce). Opening the second slit makes it clear that light behaves like a wave, since interference is a wave phenomenon.Yet each photon is found to land, whole and undivided, in a tiny region, like a particle would. Even when photons are emitted one at a time, they still form the double-slit interference pattern. Does a single photon interfere with itself?

This is not what Young observed.

Instead, the light created, on a screen beyond the slitted curtain, a pattern of zebra stripes, alternating dark and light vertical bands. It's called an *interference pattern*. Its genesis was clear: where crests of light waves from one slit met crests of waves from the other, the waves reinforced each other, producing the bright bands. Where the crest of a wave from one slit met the trough of a wave from the other, they canceled each other, producing the dark bands. Since the crests and troughs of a light wave are not visible to the naked eye, this is easier to visualize with water waves. Place a barrier with two openings in a pool of water. Drop a heavy object into the pool—watermelons work—and observe the waves on the other side of the barrier. As they radiate out from the watermelon splash, the ripples form nice concentric circles. When any ripple reaches the barrier, it passes through both openings and, on the other side, resumes radiating, now as concentric half-circles. Where a crest of ripples from the left opening meets a crest of ripples from the right, you get a double-height wave. But where crest meet trough, you get a zone of calm. Hence Young's interpretation of his double-slit experiment: if light produces the same interference patterns as water waves, which we know to be waves, then light must be a wave, too. For if light were particulate, it would produce not the zebra stripes he saw but, rather, the sum of the patterns emerging from the two slits when they are opened separately—two splotches of light, perhaps, like the marbles thrown at our broken fence.

So far, so understandable. But, for the next trick, turn the light source way, way down so that it emits but a single photon, or light particle, at a time. (Today's photodetectors can literally count photons.) Put a photographic plate on the other side, beyond the slits. Now we have a situation more analogous, it would seem, to the marbles going through the fence: zip goes one photon, perhaps making it through a slit. Zip goes the next, doing the same. Surely the pattern produced would be the sum of the patterns produced by opening each slit separately—again, perhaps two intermingled splotches of light, one centered behind the left slit and the other centered behind the right.

But no.

As hundreds and then thousands of photons make the journey (this experiment was conducted by physicists in Paris in the mid-1980s), the pattern they create is a wonder to behold. Instead of the two broad patches of light, after enough photons have made the trip you see the zebra stripes. The interference pattern has struck again. But what interfered with what? This time the photons were clearly particles—the scientists counted each one as it left the gate—and our apparatus allowed only a single photon to make the journey at a time. Even if you run out for coffee between photons, the result is eventually the same interference pattern. Is it possible that the photon departed the light source as a particle and arrived on the photographic plate as a particle (for we can see each arrive, making a white dot on the plate as it lands)—but in between became a wave, able to go through both slits at once and interfere with itself just as a water wave from our watermelon goes through the two openings in the barrier? Even weirder, each photon—and remember, we can release them at any interval—manages to land at precisely the right spot on the plate to contribute its part to the interference pattern.

So, to recap, we seem to have light vacillating between a parti-clelike existence and a wavelike one. As a particle, the light is emitted and detected. As a wave, it goes through both slits at once. Lest you discount this as just some weird property of light and not of matter, consider this: the identical experiment can be done with electrons. They, too, depart the source (an electron microscope, in work by a team at Hitachi research labs and Gakushuin University in Tokyo) as particles. They land on the detector—a scintillation plate, like the front of a television screen, which records each electron arrival as a minuscule dot—as particles. But in between they act as waves, producing an interference pattern almost identical to that drawn by the photons. Dark stripes alternate with bright ones. Again, the only way single electrons can produce an interference pattern is by acting as waves, passing through both slits at once just as the photons apparently did. Electrons—a form of matter—can behave as waves. A single electron can take two different paths from source to detector and interfere with itself: during its travels it can be in two places at once. The same experiments have been performed with larger particles, such as ions, with the identical results. And ions, as we saw back in Chapter 3, are the currency of the brain, the particles whose movements are the basis for the action potential by which neurons communicate. They are also, in the case of calcium ions, the key to triggering neurotransmitter release. This is a crucial point: ions are subject to all of the counterintuitive rules of quantum physics.

The behavior of material particles means that these particles have associated waves. Like a wave in water, the electron wave goes through both slits and interferes with itself on the other side. The interference pattern at the detector defines the zebra pattern. Particles travel through the hole as waves but arrive as particles. How can we reconcile these disparate properties of such bits of matter as electrons? A key to understanding the whole bizarre situation is that we actually measure the photon or electron at only two points in the experiment: when we release it (in which case a photodetec-tor counts it) and when we note its arrival at the end. The conventional explanation is that the act of measurement makes a spread-out, fuzzy wave (at the slits) collapse into a discrete, definite particle (on the scintillation plate or other detector). According to quantum theory, what in fact passes through the slits is a wave of probability. In fact, quantum physics describes the behavior of a particle by something called the Schrödinger wave equation (after Erwin Schrödinger, who conceived it in 1926). Just as Newton's second law describes the behavior of particles, so *Schrödinger's wave equation* specifies the continuous and smooth evolution of the wave function at all times when it is not being observed. The wave function encodes the entire range of possibilities for that particle's behavior—where the particle is, when. It contains all the information needed to compute the probabilities of finding the particle in any particular place, any time. These many possibilities are called superpositions. The element of chance is key, for rather than specifying the location, or the energy, or any other trait of a particle, the equation modestly settles for describing the probability that those traits will have particular values. (In precise terms, the square of the amplitude of the wave function at any given position gives the probability that the particle will be found in some region near that position.) In this sense the Schrödinger wave can be considered a probability wave.

When a quantum particle or collection of particles is left alone to go its merry way unobserved, its properties evolve in time and space according to the deterministic wave equation. At this point (that is, before the electron or photon is observed), the quantum particle has no definite location. It exists instead as a fog of probabilities: there are certain odds (pretty good ones) that, in the appropriate experiment, it will be in the bright bands on the plate, other odds (lower) that it will land in the dark bands, and other odds (lower still, but nonzero) that it will be in the Starbucks across the street. But as soon as an observer performs a measurement—detecting an electron landing on a plate, say—the wave function seems to undergo an abrupt change: the location of the particle it describes is now almost definite. The particle is no longer the old amalgam of probabilities spread over a large region. Instead, if the observer sees the electron in *this* tiny region, then only that part of the wave function representing the small region where observation has found it survives. Every other probability for the electron's position has vanished. Before the observation, the system had a range of possibilities; afterward, it has a single actuality. This is the infamous *collapse of the wave function*.

There is, to put it mildly, something deeply puzzling about the collapse of the wave function. The Schrödinger equation itself contains no explanation of how observation causes it; as far as that equation is concerned, the wave function goes on evolving forever with no collapse at all. And yet that does not seem to be what happens. All that we know from experiment and hard-nosed mathematical calculations is that the Schrödinger wave equation, describing a microworld of superposed wave functions, somehow becomes a macroworld of definite states. In sharp contrast to the unqualified success of quantum physics in predicting the outcome of experiments stands the mess of diverse opinion that lies under the umbrella "interpretations of quantum mechanics": what happens to turn the Schrödinger wave equation into a single observed state, and what does that process tell us about the nature of reality?

There are at least three ways to account for the shift from a microworld of probabilities defined by the Schrödinger wave equations to a macroworld of definite states that we measure. Each interpretation implies a different view of the essential nature of the world. One view, preferred by Einstein, holds that the world is governed by what are called *hidden variables*. Although so-far undiscovered and perhaps even undiscoverable (hence the *hidden* part), they are supposed to be the certainties of which the wave function of quantum physics describes the probabilities. This view can be thought of as the way a tank of goldfish might think about the arrival every day of food flakes drifting through their water. It seems to be random, and without cause. There is (say) a fifty-fifty chance that food will arrive before the shadow of a little plastic skin diver reaches the little plastic mermaid, and a fifty-fifty chance that the food will land later. If only our little finned friends knew more about the world, they would understand that the arrival of the food is completely causal (the human walks over and sprinkles flakes on the water's surface). The hidden variables view, in other words, says that things look probabilistic only because we are too stupid to identify the forces that produce determinism. If we were more clever, we would see that determinism rules. Einstein's beliefs tended in this direction, leading him to his famous pronouncement "God does not play dice" with the universe. Einstein notwithstanding, however, hidden variables have been out of favor since the 1960s, for reasons too technical to get into. Suffice it to say that the physicist John Bell showed that hidden variables require instantaneous action at a distance—that is, causal influences that break the Einsteinian speed limit and travel faster than the speed of light.

A second interpretation of quantum physics holds that superposed waves exist for quantum phenomena, all right, but never really collapse. This *many-worlds view* is the brainchild of the late physicist Hugh Everett III, a student of John Wheeler, who suggested it at Wheeler's urging in a 1957 paper. Instead of attempting to answer how the act of observation induces the wave function to collapse into a single possibility, the many-worlds view holds that no single possibility is ever selected. Rather, the wave function continues evolving, never collapsing at all. How, then, do we manage to see not superpositions—electrons that are a little bit here and a little bit there—but discrete states? Every one of the experiential possibilities inherent in the wave function is realized in some superrealm, Everett proposed. If the wave function gives a fifty-fifty probability that a radioactive atom will decay after thirty minutes, then in one world the atom has decayed and in another it has not. Correspondingly, the mind of the observer has two different branches, or states: one perceiving an intact atom and the other perceiving a decayed one. The result is two coexisting parallel mental realities, the *many-minds view*. Every time you make an observation or a choice your conscious mind splits so that, over time, countless different copies of your mind are created. This, needless to say, is the ultimate in having your cake and eating it, too: sure, you may have uttered that career-ending epithet in this branch of reality, but in some other branch you kept your mouth shut.

From its inception, this theory caused discomfort. "For at least thirteen years after Everett's paper was published, there was a deafening silence from the physics community," recalls Bryce DeWitt, a physicist who championed the many-worlds view even into his eighties. "Only John Wheeler, Everett, and I supported it. I thought Everett was getting a raw deal."

As a psychiatrist I was certainly familiar with the idea of a split personality, but here was an interpretation of quantum mechanics that took the concept absolutely literally. Many scholars investigating the ontological implications of quantum mechanics squirm at the notion that all possible experiences occur, and that a new world and a new version of each observer's mind are born every time a quantum brain reaches a choice point. But many others prefer this bizarre scenario to the idea of a sudden collapse of the wave function. They like, too, that many-worlds allows quantum mechanics to operate without requiring an observer to put questions to nature—that is, without human consciousness and free choice rearing their unwelcome heads, and without the possibility that the human mind can affect the physical world. In fact, at a 1999 quantum conference in England, of ninety physicists polled about which interpretation of quantum mechanics they leaned toward, thirty chose many-worlds or another interpretation that includes no collapse. Only eight said they believed that the wave function collapses. But another fifty chose none of the above. (And of course, if they were honest, the ones who chose many-worlds would have to believe they had simultaneously made a near-infinity of different choices on their other branches.)

A third view of the change from superpositions to a single definite state is the one advanced by Niels Bohr. In this case, the abrupt change from superpositions to single state arises from the act of observation. This is the interpretation that emerged in the field's earliest days. During a period of feverishly intense creativity in the 1920s, the greatest minds in physics, from Paul Dirac and Niels Bohr to Albert Einstein and Werner Heisenberg, struggled to explain the results of quantum experiments. Finally, at the fifth Solvay Congress of physics in Brussels 1927, one group—Bohr, Max Born, Paul Dirac, Werner Heisenberg, and Wolfgang Pauli—described an accord that would become known as the Copenhagen Interpretation of quantum mechanics, after the city where Bohr, its chief exponent, worked. Bohr insisted that quantum theory is about our knowledge of a system and about predictions based on that knowledge; it is not about reality "out there." That is, it does not address what had, since before Aristotle, been the primary subject of physicists' curiosity—namely, the "real" world. The physicists threw in their lot with this view, agreeing that the quantum state represents our knowledge of a physical system.

Before the act of observation, it is impossible to know which of the many probabilities inherent in the Schrödinger wave function will become actualized. Who, or what, chooses which of the probabilities to make real? Who, or what, chooses how the wave function "collapses"? Is the choice made by nature, or by the observer? According to the Copenhagen Interpretation, it is the observer who both decides which aspect of nature is to be probed and reads the answer nature gives. The mind of the observer helps choose which of an uncountable number of possible realities comes into being in the form of observations. A specific question (Is the electron here or there?) has been asked, and an observation has been performed (Aha! the electron is there!), corralling an unruly wave of probability into a well-behaved quantum of certainty. Bohr was silent on how observation performs this magic. It seems, though, as if registering the observation in the mind of the observer somehow turns the trick: the mental event collapses the wave function. Bohr, squirming under the implications of his own work, resisted the idea that an observer, through observation, is actually influencing the course of physical events outside his body. Others had no such qualms. As the late physicist Heinz Pagels wrote in his wonderful 1982 book *The Cosmic Code*, "There is no meaning to the objective existence of an electron at some point in space…independent of any actual observation. The electron seems to spring into existence as a real object only when we observe it!"

Physical theory thus underwent a tectonic shift, from a theory about physical reality to a theory about our knowledge. Science is what we know, and what we know is only what our observations tell us. It is unscientific to ask what is "really" out there, what lies behind the observations. Physical laws as embodied in the equations of quantum physics, then, ceased describing the physical world itself. They described, instead, our knowledge of that world. Physics shifted from an ontological goal—learning what is—to an epistemological one: determining what is known, or knowable. As John Archibald Wheeler cracked, "No phenomenon is a phenomenon until it is an observed phenomenon." The notion that the wave function collapses when the mind of an observer registers a new bit of knowledge was developed by the physicist Eugene Wigner, who proposed a model of how consciousness might collapse the wave function—something we will return to. But why human consciousness should be thus privileged has remained an enigma and a source of deep division in physics right down to today.

It is impossible to exaggerate what a violent break this represented. Quantum physics had abandoned the millennia-old quest to understand what exists in favor of our knowledge of what exists. As Jacob Bronowski wrote in *The Ascent of Man*, "One aim of the physical sciences has been to give an exact picture of the material world. One achievement of physics in the twentieth century has been to prove that that aim is unattainable." The Copenhagen Interpretation drew the experiences of human observers into the basic theory of the physical world—and, even more, made *them* the basic realities. As Bohr explained, "In our description of nature the purpose is not to disclose the real essence of phenomena but only to track down as far as possible relations between the multifold aspects of our experience." With this shift, Heisenberg said, the concept of objective reality "has thus evaporated." Writing in 1958, he admitted that "the laws of nature which we formulate mathematically in quantum theory deal no longer with the particles themselves but with our knowledge of the elementary particles." "It is wrong," Bohr once said, "to think that the task of physics is to find out how nature is. Physics concerns what we can say about nature."

To many, this surrender was nothing short of heresy. Einstein, perhaps the most passionate opponent of the abandonment of efforts to understand nature, objected that this shift from what exists to what we know about what exists violated what he considered to be "the programmatic aim of all physics," namely, a complete description of a situation independent of any act of observation. But Einstein lost. With the triumph of quantum, physics stopped being about nature itself and instead became about our knowledge of nature.

Right about here every discussion of quantum epistemology invokes Schrödinger's cat, a thought experiment that Schrödinger proposed in 1935 to illustrate the bewilderments of quantum superpositions. Put a pellet inside a box, he said, along with a radioactive atom. Arrange things so that the pellet releases poison gas if and only if the atom decays. Radioactive decay is a quantum phenomenon, and hence probabilistic: a radioactive atom has a finite probability of decaying in a certain window of time. In thirty minutes, an atom may have a 50 percent chance of decaying—not 70 percent, not 20 percent, but precisely 50 percent. Now put a cat in the box, and seal it in what Schrödinger called a "diabolical device." Wait a while. Wait, in fact, a length of time equal to when the atom has a fifty-fifty chance of decaying. Is the cat alive or dead?

Quantum mechanics says that the creature is both alive and dead, since the probability of radioactive decay and hence release of poison gas is 50 percent, and the possibility of no decay and a safe atmosphere is also 50 percent. Yet it seems absurd to say that the cat is part alive and part dead. Surely a physical entity must have a real physical property (such as life or death) ? If we peek inside the box, we find that the cat is alive or dead, not some crazy superposition of the two states. Yet surely the act of peeking should not be enough to turn probability into actuality? According to Bohr's Copenhagen Interpretation, however, this is precisely the case. The wave function of the whole system, consisting of kitty and all the rest, collapses when an observer looks inside. Until then, we have a superposition of states, a mixture of atomic decay and atomic intactness, death and life.

Observations, to put it mildly, seem to have a special status in quantum physics. So long as the cat remains unobserved, its wave function encodes equal probabilities of life and death. But then an observation comes along, and *bam*—the cat's wave function jumps from a superposition of states to a single observed state. Observation lops off part of the wave function. The part corresponding to living or deceased, but not the other, survives.

If the power of the observer to coax a certain value out of a probability wave sounds like the wrong answer to the question of whether a tree falls in an empty wood even if no one hears it, take heart: physicists are just as puzzled about how the world can work in such a bizarre way. As Eugene Wigner stated in 1964, "This last step [the entering of an observation into consciousness] is…shrouded in mystery and no explanation has been given for it so far." The collapse of the wave function, which gives rise to the centrality of consciousness in physical theory, "enters quantum mechanical theory as a deus ex machina, without any relation to the other laws of this theory."

One of the things I admired about Stapp's *Mind, Matter and Quantum Mechanics* was his willingness to address the ethical implications of the change from Newtonian physics to quantum physics. In particular, Stapp made the point that there is no stronger influence on human values than man's belief about his relationship to the power that shapes the universe. When medieval science connected man directly to his Creator, man saw himself as a child of the divine imbued with a will free to choose between good and evil. When the scientific revolution converted human beings from the sparks of divine creation into not particularly special cogs in a giant impersonal machine, it eroded any rational basis for the notion of responsibility for one's actions. We became a mechanical extension of what preceded us, over which we have no control; if everything we do emerges preordained by the conditions that prevail, then we can have no responsibility for our own actions. "Given this conception of man," Stapp argued, "the collapse of moral philosophy is inevitable." But just as Newtonian physics undermines moral philosophy, Stapp thought, so quantum physics might rescue it. For quantum physics describes a world in which human consciousness is intimately tied into the causal structure of nature, a world purged of determinism.

Impressed by what seemed a kindred mind, I therefore e-mailed Stapp on March 2, 1998, introducing myself as a friend of Chalmers (whom Stapp had met several times) and telling him that I "had started reading your book Mind Matter and QM—I'm still working on it and finding it of great importance." Stapp responded on March 10, with requests for some of my reprints. In a phone call soon after, we discussed, among other things, how Newtonian approaches had evolved so as to stifle morality, and why science was therefore vastly overrated as a force for good. Stapp, a courtly man, seemed sympathetic (if not as passionate as I about all this), and we arranged to get together. On June 9, I drove my old used 1988 copper Mercedes up to Berkeley and met Henry for the first time and spent the afternoon in his office. At a long dinner that evening at a restaurant hard by the railroad tracks on the outskirts of Berkeley, the conversation ranged from quantum mechanics to phantom pain, from statistical tests of the paranormal to the attempts by some theologians to find spiritual messages in the discoveries of cosmologists. (That week, Berkeley was hosting a symposium, "Science and the Spiritual Quest.")

Back home, I was juggling a couple of tasks. Although I had only a rudimentary understanding of quantum physics at the time I tackled Stapp's 1993 book, its relevance to the mind-brain question, and to my interpretation of the OCD brain data, made it clear that I needed to learn a whole lot more. Quantum mechanics seems to contain a role for consciousness in the physical world. Fortunately, Stapp's book, as well as papers for nonphysicists that he posted on his web site, addressed those questions in accessible, if not entirely elementary, ways. Even better, Stapp himself is the soul of patience, who proved to be extraordinarily open to question-and-answer sessions by phone and e-mail. And so, over the next two and a half years, I slowly got a handle on key physics concepts supporting the causal efficacy of volition and attention. In a September 7, 1998, phone conversation, Stapp told me, "In quantum theory, experience is the essential reality, and matter is viewed as a representation of the primary reality, which is experience." I wrote it down verbatim and tacked it on my office wall, where it still hangs today.

As I worked to deepen my understanding of quantum mechanics, I was also trying to apply the basic structure of Stapp's physics reasoning to a philosophical paper I was writing about the OCD work. In April, I had presented a paper at a conference that Dave Chalmers had helped organize at the University of Arizona's Tucson campus, "Toward a Science of Consciousness." I had spoken about my OCD work, particularly the "mind can change brain" aspects. Now, in June, I was in the midst of turning the oral presentation into a paper for the conference proceedings. In addition, A *Return to Innocence* was in galleys at this point, on track for a September 1998 publication. The combination of the book, in which I used "mental force" as a literary device, plus my philosophically grounded reanalysis of the PET scans of my OCD patients for the Tucson paper, created a powerful alchemy. As I turned over in my mind yet again the four steps I taught my OCD patients to go through when in the throes of a compulsion—Relabel, Reattribute, Refocus, Revalue—it occurred to me that mental force might be more than just a way to help readers of *Return to Innocence* understand how mindfulness and directed effort can help reshape the way they think and behave. To the contrary: there was nothing about mental force as I conceived it that condemns it to be just a metaphor. Whether it had any genuine scientific import, I had no idea—not yet, anyway.

But Stapp might. My manuscript contained the first use of "mental force" in more than a metaphorical sense and marked the first time I had used it in a scientific paper. On June 21, I e-mailed Stapp that I was writing something he might consider beyond the pale: "I know I took some serious risks with my use of the concepts of energy, power and force,…so I'll definitely need your feedback on that—hopefully you'll still be willing to talk to me after you see it." Three days later, I prepared to e-mail the paper to Stapp to get his reaction. I stared at the computer screen for what seemed like ages before I could screw up my courage to hit "send." I think this is pretty good, I thought, but considering what I know about physics and forces I might be about to embarrass myself royally.

Stapp replied by e-mail on June 25: "Your draft was masterful," he wrote.

It should act to focus the attention of workers in this field on the fact that THE fundamental issue before us, namely the question of the efficacy of consciousness, need not be walked away from as something totally intractable. Your work makes it clear that "will" involves different levels or aspects of consciousness, with higher-level experiences presiding over lower-level experiences in much the way that the "subjective I" controls bodily actions…. In this connection, it may be important that the key issue in the interpretation of quantum theory is "at what level do the collapses occur?"…The quality of the experience of "will" strongly suggests that [it]…acts on the physical level…. Contemporary quantum theory is built on experience, and makes no sense without experience…. Within the richer theoretical framework "will will almost certainly be efficacious.

Henry Stapp had been interested, since his student days, in what has come to be called the interpretation of quantum theory. When Wolfgang Pauli visited UC Berkeley to deliver a series of lectures in 1958, the physics department, as was customary, assigned a postdoc to take lecture notes. Stapp got the nod. That put him in frequent and close contact with Pauli, who invited Stapp to go to Zurich to work with him. Stapp arrived in the fall of 1958, but Pauli died that December. Since Stapp's fellowship was to last six months, he found himself with unexpected time on his hands. He used it to delve into the work of the mathematician John von Neumann, in particular his book on the foundations of quantum theory. This work raised in Stapp's mind questions about the role of mind in physics. In 1959, still in Zurich, he foreshadowed his later book by writing an essay, "Mind, Matter and Quantum Mechanics," in which he discussed the notion that reality comes into being only when an observer observes it. But he also recognized serious problems with this idea. In 1965, when the United States sent the unmanned *Mariner 4* probe to pass by Mars, Stapp asked, Are we to believe that a mountain on Mars springs into existence only when some guy at mission control calls up *Mariner's* imaging data on the console screen? Like most others, Stapp resisted von Neumann's suggestion that mind had anything to do with creating reality. But he continued to ponder the mystery of what turned all of the potentials embodied in the Schrödinger wave function into a single observed reality.

Back in Berkeley, this was the challenge Stapp took up. "I worked long and hard trying to figure out what led to the collapse of the wave function. In the end, I became more convinced that conscious experiences needed to be taken seriously," he recalls. In 1968, Stapp went to Munich, where he became engrossed in discussions with Heisenberg about his and Bohr's more philosophical papers. "Then as now, physicists pay lip service to these writings, but quantum physics is taught as engineering," says Stapp. "This is how you apply it and these are the mathematical rules. The philosophy is brushed under the rug; you don't try to think what's really happening." Or as physicists sometimes put it: "Don't think. Calculate."

But Stapp was deeply curious about the philosophy implied by quantum physics, and whether in fact the act of observation has a hand in bringing about one possible reality rather than another. “When I came to Munich I was filled with lots of questions,” he recalls.

I had quite a few discussions with Heisenberg, and came to realize that his and Bohr’s positions were not the same. Heisenberg talked in terms of propensities or tendencies for an event to occur, which would happen even if an observer were not there. This is the common understanding of quantum theory by most practitioners, who almost to a man do not believe that human observers have much to do with this. Heisenberg separated himself from [Bohr’s] interpretation by being willing to discuss what is actually happening, in spite of the fact that the official doctrine says you are not supposed to talk about that. He acknowledged that, but said this is nevertheless “what I think.”

Heisenberg believed that the infamous cat was indeed either alive or dead, even before an observer looked and collapsed the wave function; it is nature herself who collapses the wave function. “It was very useful for me to hear right from him that there was not total agreement” on the role of the observer, Stapp says. “I came to realize that the interpretation of quantum physics, particularly the underlying ontology, was not totally worked out.”

Shortly after his discussions with Heisenberg, Stapp was returning from Europe and had to overnight in London. He walked to a park and settled in on a bench with William James’s *The Meaning of Truth*. What he read produced an epiphany. “That was when it all came together,” says Stapp. “James argues that we’ll never know for sure the absolute truth, and that science is therefore provisional. In the end all you can do is say how well your theories are working. Once I read James’s idea, it allowed me to understand what Bohr was saying,” with his conclusion that we cannot know what really happens, but only what we observe to happen. Was the Danish physicist (who died in 1962) familiar with the work of the American psychologist? The science historian Thomas Kuhn once asked Bohr whether there was any connection between his ideas and James’s. Bohr responded, “Yes, it’s all coming back; we’ll talk about that tomorrow.” He died that very night, November 18, taking the answer with him.

As Stapp interpreted quantum mechanics, the observer plays two roles. He experiences the output of the measuring devices, of course—the clicks of the Geiger counter in our radioactive atom experiment, for instance. What he records depends on which choice nature has made: the atom decays or it doesn’t. This is known as the Dirac choice after P. A. M. Dirac, the English physicist who, at the fifth Solvay Congress of physics in Brussels in 1927, conceptualized this random event as a choice by nature (but is better known for predicting the existence of antimatter). It is, as far as physicists know, a truly random choice. But the observer plays another role: he chooses which questions to pose to nature. Stapp named this the Heisenberg choice, because Heisenberg stressed it at the 1927 congress. “In quantum theory,” Stapp says, “the observer must decide which question to put to nature, which aspect of nature his inquiry will probe. A person’s conscious thoughts can and…must…play a role that is not reducible to the combination of the Schrödinger and Dirac processes." Until a question is posed, nothing happens. Without some way of specifying what the question is, the quantum process seizes up like a stuck gear and grinds to a halt. There is, then, a three-part process: the evolution of the wave equation as described by the Schrödinger equation, the choice of which question to pose (the Heisenberg choice), and nature's statistical choice of which answer to give (the Dirac choice).

This three-part description of quantum mechanics had never been presented publicly in any detail when, in July 1999, Stapp and I, along with Dave Chalmers and a host of renowned physicists, neuroscientists, and philosophers, ascended into the cool clear mountain air of Flagstaff, Arizona, for a conference, "Quantum Approaches to Consciousness." I eagerly looked forward to this meeting, both because of its lovely Grand Canyonesque location and because I knew that here, before a solemn (well, at least during the daytime sessions) gathering, Stapp would tackle the thorny question of how the probabilities described by the Schrödinger equation collapse into the actualities we observe and measure. Eugene Wigner, as I hinted earlier, followed the new realizations to their inevitable conclusion. "The laws of quantum mechanics cannot be formulated…without recourse to the concept of consciousness," he wrote in 1961. Matter has become intrinsically connected to subjective experiences. And that leads to a profound implication. It makes little sense, Wigner argued, to describe the mind and consciousness in terms of the positions of atoms, for one simple reason: the latter are derived from the former and have no fixed and non-probabilistic existence outside the former. "It seems inconsistent," Wigner said in 1969, "to explain the state of mind of [an] observer…in terms of concepts, such as positions of atoms, which have to be explained, then, in terms of the content of consciousness." If the positions of atoms (and thus, for our purposes, the state and arrangement of neurons, since neurons are only collections of zillions of atoms) have no unambiguous existence independent of the consciousness of an observer, Wigner asked, then how can that very consciousness depend on those same atoms? "The extreme materialistic point of view…is clearly absurd and…is also in conflict with the tenets of quantum mechanics," he concluded.

Classical physics had no way to account for consciousness; Copenhagen brought in consciousness, all right, but at the ghastly price of substituting it for objective reality. The von Neumann/ Wigner theory that Stapp referred to in his first e-mail to me, in 1998, seemed to offer a way out. Eugene Wigner and John von Neumann had joined the wave of refugees fleeing Hitler and had wound up at Princeton University. In 1932, von Neumann formulated a new version of quantum mechanics. Its main point of departure from the Copenhagen Interpretation is this: Copenhagen describes measuring devices (things like Geiger counters and scintillation counters as well as the human brain that registers the results of those measurements) in Newtonian rather than quantum terms. This makes the theory inherently inconsistent, since one part of the physical world (subatomic particles) gets the quantum treatment but the rest of the physical world (lab equipment and brains) stays Newtonian. And yet the stuff in the second group is made of the same atoms and subatomic particles as the stuff in the first. Von Neumann realized that this made no sense: a measuring device is not intrinsically different from the atoms that make it up. So he fixed the problem. In the mathematical rules of quantum theory he worked out, he first incorporated measuring devices, so that when physicists did a calculation they would have to apply quantum rules to these devices. And then he incorporated everything made of atoms and their constituents—in particular, the human brain. In von Neumann's formulation, every experiential event, such as reading a measuring device or otherwise making an observation, has a corresponding brain event. No surprise there. But von Neumann went further: the brain, he argued, operates according to the rules of quantum mechanics.

Applying quantum theory to the brain means recognizing that the behaviors of atoms and subatomic particles that constitute the brain, in particular the behavior of ions whose movements create electrical signals along axons and of neurotransmitters that are released into synapses, are all described by Schródinger wave equations. Thanks to superpositions of possibilities, calcium ions might or might not diffuse to sites that trigger the emptying of synaptic vesicles, and thus a drop of neurotransmitter might or might not be released. The result is a whole slew of quantum superpositions of possible brain events. When such superpositions describe whether a radioactive atom has disintegrated, we say that those superpositions of possibilities collapse into a single actuality at the moment we observe the state of that previously ambiguous atom. The resulting increment in the observer's knowledge of the quantum system (the newly acquired knowledge that the atom has decayed or not) entails a collapse of the wave functions describing his brain. This point is key: once the brains of observers are included in the quantum system, the wave function describing the state of the brain of any observer collapses to the form corresponding to his new knowledge. The quantum state of the brain must collapse when an observer experiences the outcome of a measurement. The collapse occurs in conjunction with the conscious act of experiencing the outcome of the observation. And it occurs in the brain of the observer—the observer who has learned something about the system.

What do we mean by collapsing the quantum state of the brain? Like the atom threatening Schrödinger's cat, the entire brain of an observer can be described by a quantum state that represents all of the various possibilities of all of its material constituents. That brain state evolves deterministically until a conscious observation occurs. Just before an observation, both the observed quantum system (let's stick with the radioactive atom) and the brain that observes it exist as a profusion of possible states. Think of each possible state as a branch on a tree. Each branch corresponds to some possible state of knowledge, or course of action. But when an observation registers in the mind of the observer, the branches are brutally pruned: only the branches compatible with the observer's experience remain. If, say, the observation is that the sun is shining, then the associated physical event is the updating of the brain's representation of the weather. Branches corresponding to "the sky is overcast" are chopped off. An increase in knowledge is accompanied by an associated reduction of the quantum state of the brain. And with that, the quantum brain changes, too.

Because the observer's only freedom is the choice of which question to pose (Shall I look up at the sky?), it is here that the mind of the observer has a chance to affect the dynamics of the brain. An examination of the mathematics, Stapp argued, shows that "the conscious intentions of a human being [reflected in the choices he makes about what question to put to nature] can influence the activities of his brain…. Each conscious event picks out from the multitude of…possibilities that comprise the quantum brain the subensem-ble that is compatible with the conscious experience." The physical event reduces the state of the brain to that branch of it that is compatible with the particular experience or observation.

Each of the principal interpretations of quantum theory—hidden variables, many-worlds, the dynamical role of consciousness, von Neumann's application of quantum rules to the brain—has its passionate partisans. For many physicists, unfortunately, which interpretation they subscribe to seems to be more a matter of intellectual fashion and personal taste than rigorous analysis. So is whether they bother with interpretation at all. Just as many neuroscientists are perfectly happy to sweep the question of consciousness under the rug and stick to something they can measure and manipulate—the brain—so a similar attitude prevails among physicists (though physicists may not be quite so oblivious as neuroscientists. "It is surprising," Wigner dryly noted, "that biologists are more prone to succumb to the error of disregarding the obvious than are physicists"). Engineers who design or use transistors, which exploit quantum phenomena, rarely think about the ontological implications of quantum mechanics and whether the mind shapes reality; neither do high-energy physicists, as they work out the chain of reactions in a particle accelerator. For every hundred scientists who use quantum mechanics, applying the standard equations like recipes, probably no more than one ponders the philosophy of it. They don't have to. You can do perfectly good physics if you just "shut up and calculate," as the physicist Max Tegmark puts it. Physicists can safely continue to believe in classical epistemology and ontology, whether consciously or not, and stash the epistemology and ontology demanded by quantum mechanics in a rarely opened room of their mind like an ugly lamp exiled to Grandma's attic. "The reason I went into physics was my fascination with the fundamental issues raised by quantum mechanics, but I quickly realized the subject was taboo," recalls Tegmark. "Real physicists just didn't spend time on these questions, and you realize pretty quickly that you can't get a job doing this. So what I would do is write quantum papers secretly, when no one knew what I was doing. When I was a grad student at Berkeley, I would make sure my adviser was far away from the printer when I printed them out."

The reluctance of most physicists to face, let alone explore, the interpretation and philosophical implications of quantum mechanics has had an unfortunate consequence. Scientists in other fields, many of whom consider physics the most basic of all sciences and the one with whose tenets their own findings must accord (an attitude sometimes denigrated as "physics envy"), have remained, for the most part, painfully naïve about the revolutionary implications of quantum theory. For neuroscientists, this ignorance exacts a price: the view of reality demanded by quantum physics challenges the validity of the Cartesian separation of mind and material world, for in the quantum universe "there is no radical separation between mind and world." As Wolfgang Pauli stated in a letter to Niels Bohr in 1955, "In quantum mechanics…an observation here and now changes in general the 'state' of the observed system…. I consider the unpredictable change of the state by a single observation…to be an abandonment of the idea of the isolation of the observer from the course of physical events outside himself." This is the textbook position on quantum mechanics and the nature of reality: that the Cartesian separation of mind and matter into two intrinsically different "substances" is false.

Ignoring quantum physics thus deprives both philosophers and neuroscientists of an avenue into, if not a way out of, the mystery of mind's relationship to matter. The unfortunate result, as we're seeing, is the belief that interactions among large assemblies of neurons are causally sufficient to account for every aspect of mind. As the philosopher Daniel Dennett put it, "A brain was always going to do what it was caused to do by local mechanical disturbances." In this view, mind is indeed nothing more than billions of interacting neurons—in short, nothing more than brain processes. There is no power we ascribe to mind—even what we experience as the power to choose, to exert the will in a way that has measurable consequences—that is not completely accounted for by electrochemistry. Most attempts to resolve the mind-matter problem, derived as they are from a Newtonian worldview, dismiss both consciousness and will as illusions, products of human fallibility or hubris. And yet such conclusions, built as they are on an outdated theory of the physical world, are built on a foundation of sand. The classical formulations are wrong "at the crucial point of the role of human consciousness in the dynamics of human brains," Stapp argues. If the mind-brain problem has resisted resolution for three centuries, it is because the physical theory that scientists and philosophers have wielded is fundamentally incorrect. If we are foundering in our attempts to resolve the mind-matter problem, the fault lies with the physics more than with the philosophy or the neuroscience. In other words, we are not doing all that badly in our efforts to understand the mind side of the equation; it's our understanding of the role of matter that is seriously off. For this, we can thank the materialist view that grew to predominance over the last three centuries.

The more I talked with Stapp throughout the summer of 1998, the more I became convinced that quantum physics would provide the underpinning for the nascent idea of mental force. The fact that the collapse of the wave function so elegantly allows an active role for consciousness—which is required for an intuitively meaningful understanding of the effects of effort on brain function—is itself strong support for using a collapse-based interpretation in any scientific analysis of mental influences on brain action. In my discussions with Stapp, it became clear that a genuine scientific synergy was possible. It would not be just my OCD patients and their PET scans, or any other data from neuroscience alone, that would drive the final nail in the coffin of materialism. It would be the integration of those data with physics. If there is to be a resolution to the mystery of how mind relates to matter, it will emerge from explaining the data of the human brain in terms of these laws—laws capable of giving rise to a very different view of the causal efficacy of human consciousness. Quantum mechanics makes it feasible to describe a mind capable of exerting effects that neurons alone cannot.

Historically, the great advances in physics have occurred when scientists united two seemingly disparate entities into a coherent, logical whole. Newton connected celestial motions with terrestrial motion. Maxwell unified light and electromagnetism. Einstein did it for space and time. Quantum theory makes exactly this kind of connection, between the objective physical world and subjective experiences. It thus offers a way out of the morass that the mind-brain debate has become, because it departs most profoundly from classical physics at a crucial point: on the nature of the dynamical interplay between minds and physical states, between physical states and consciousness. It ushers the observer into the dynamics of the system in a powerful way. Following quantum theory into the thicket of the mind-matter problem actually leads to a clearing, to a theory of mind and brain that accords quite well with our intuitive sense of how our mind works. In Stapp's formulation, quantum theory creates a causal opening for the mind, a point of entry by which mind can affect matter, a mechanism by which mind can shape brain. That opening arises because quantum theory allows intention, and attention, to exert real, physical effects on the brain, as we will now explore.