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Inventing the Universe

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Two new books on quantum theory could not, at first glance, seem more different. The first, *Something Deeply Hidden*, is by Sean Carroll, a physicist at the California Institute of Technology, who writes, "As far as we currently know, quantum mechanics isn't just an approximation of the truth; it is the truth." The second, *Einstein's Unfinished Revolution*, is by Lee Smolin of the Perimeter Institute for Theoretical Physics in Ontario, who insists that "the conceptual problems and raging disagreements that have bedeviled quantum mechanics since its inception are unsolved and unsolvable, for the simple reason that the theory is wrong."

Something Deeply Hidden: Quantum Worlds and the Emergence of Spacetime
By Sean Carroll
Dutton ~ 2019 ~ 347 pp.
$29 (cloth)

Einstein's Unfinished Revolution: The Search for What Lies Beyond the Quantum
By Lee Smolin
Penguin ~ 2019 ~ 322 pp.
$28 (cloth)

Given this contrast, one might expect Carroll and Smolin to emphasize very different things in their books. Yet the books mirror each other, down to chapters that present the same quantum demonstrations and the same quantum parables. Carroll and Smolin both agree on the facts of quantum theory, and both gesture toward the same historical signposts. Both consider themselves *realists*, in the tradition of Albert Einstein. They want to finish his work of unifying physical theory, making it offer one coherent description of the entire world, without ad hoc exceptions to cover experimental findings that don't fit. By the end, both suggest that the completion of this project might force us to abandon the idea of three-dimensional space as a fundamental structure of the universe.

But with Carroll claiming quantum mechanics as *literally true* and Smolin claiming it as *literally false*, there must be some underlying disagreement. And of course there is. Traditional quantum theory describes things like electrons as smeary waves whose measurable properties only become definite in the act of measurement. Sean Carroll is a supporter of the "Many Worlds" interpretation of this theory, which claims that the multiple measurement possibilities all simultaneously exist. Some proponents of Many Worlds describe the existence of a "multiverse" that contains many parallel universes, but Carroll prefers to describe a single, radically enlarged universe that contains all the possible outcomes running alongside each other as separate "worlds." But the trouble, says Lee Smolin, is that in the real world as we observe it, these multiple possibilities never appear—each measurement has a single outcome. Smolin takes this fact as evidence that quantum theory must be wrong, and argues that any theory that supersedes quantum mechanics must do away with these multiple possibilities.

So how can such similar books, informed by the same evidence and drawing upon the same history, reach such divergent conclusions? Well, anyone who cares about politics knows that this type of informed disagreement happens all the time, especially, as with Carroll and Smolin, when the disagreements go well beyond questions that experiments could possibly resolve.

But there is another problem here. The question that both physicists gloss over is that of just how much we should expect to get out of our best physical theories. This question pokes through the foundation of quantum mechanics like rusted rebar, often luring scientists into arguments over parables meant to illuminate the obscure.

With this in mind, let's try a parable of our own, a cartoon of the quantum predicament. In the tradition of such parables, it's a story about knowing and not knowing.

We fade in on a scientist interviewing for a job. Let's give this scientist a name, Bobby Alice, that telegraphs his helplessness to our didactic whims. During the part of the interview where the Reality Industries rep asks him if he has any questions, none of them are answered, except the one about his starting salary. This number is high enough to convince Bobby the job is right for him.

Knowing so little about Reality Industries, everything Bobby sees on his first day comes as a surprise, starting with the campus's extensive security apparatus of long gated driveways, high tree-lined fences, and all the other standard *X-Files* elements. Most striking of all is his assigned building, a structure whose paradoxical design merits a special section of the morning orientation. After Bobby is given his project details (irrelevant for us), black-suited Mr. Smith–types tell him the bad news: So long as he works at Reality Industries, he may visit only the building's fourth floor. This, they assure him, is standard, for all employees but the top executives. Each project team has its own floor, and the teams are never allowed to intermix.

The instructors follow this with what they claim is the good news. Yes, they admit, this tightly tiered approach led to worker distress in the old days, back on the old campus, where the building designs were brutalist and the depression rates were high. But the new building is designed to subvert such pressures. The trainers lead Bobby up to the fourth floor, up to his assignment, through a construction unlike any research facility he has ever seen. The walls are translucent and glow on all sides. So do the floor and ceiling. He is guided to look up, where he can see dark footprints roving about, shadows from the project team on the next floor. "The goal here," his guide remarks, "is to encourage a sort of cultural continuity, even if we can't all communicate."

Over the next weeks, Bobby Alice becomes accustomed to the silent figures floating above him. Eventually, he comes to enjoy the fourth floor's communal tracking of their fifth-floor counterparts, complete with invented names, invented personalities, invented purposes. He makes peace with the possibility that he is himself a fantasy figure for the third floor.

Then, one day, strange lights appear in a corner of the ceiling.

Naturally phlegmatic, Bobby Alice simply takes notes. But others on the fourth floor are noticeably less calm. The lights seem not to follow any known standard of the physics of footfalls, with lights of different colors blinking on and off seemingly at random, yet still giving the impression not merely of a constructed display but of some solid fixture in the fifth-floor commons. Some team members, formerly of the same anti-philosophical bent as most hires, now spend their coffee breaks discussing increasingly esoteric metaphysics. Productivity declines.

Meanwhile, Bobby has set up a camera to record data. As a work-related extracurricular, he is able in the following weeks to develop a general mathematical description that captures an unexpected order in the flashing lights. This description does not predict exactly which lights will blink when, but, by telling a story about what's going on between the frames captured by the camera, he can predict what sorts of patterns are allowed, how often, and in what order.

Does this solve the mystery? Apparently it does. Conspiratorial voices on the fourth floor go quiet. The "Alice formalism" immediately finds other applications, and Reality Industries gives Dr. Alice a raise. They give him everything he could want—everything except access to the fifth floor.

In time, Bobby Alice becomes a fourth-floor legend. Yet as the years pass—and pass with the corner lights as an apparently permanent fixture—new employees occasionally massage the Alice formalism to unexpected ends. One worker discovers that he can rid the lights of their randomness if he imagines them as the reflections from a tank of iridescent fish, with the *illusion* of randomness arising in part because it's a 3-D projection on a 2-D ceiling, and in part because the fish swim funny. The Alice formalism offers a series of color maps showing the different possible light patterns that might appear at any given moment, and another prominent interpreter argues, with supposed sincerity (although it's hard to tell), that actually not one but *all* of the maps occur at once—each in parallel branching universes generated by that spooky alien light source up on the fifth floor.

As the interpretations proliferate, Reality Industries management occasionally finds these side quests to be a drain on corporate resources. But during the Alice decades, the fourth floor has somehow become the company's most productive. Why? Who knows. Why fight it?

The history of quantum mechanics, being a matter of record, obviously has more twists than any illustrative cartoon can capture. Readers interested in that history are encouraged to read Adam Becker's recent retelling, *What Is Real?*, which was reviewed in these pages ("Make Physics Real Again," Winter 2019). But the above sketch is one attempt to capture the unusual flavor of this history.

Like the fourth-floor scientists in our story who, sight unseen, invented personas for all their fifth-floor counterparts, nineteenth-century physicists are often caricatured as having oversold their grasp on nature's secrets. But longstanding puzzles—puzzles involving chemical spectra and atomic structure rather than blinking ceiling lights—led twentieth-century pioneers like Niels Bohr, Wolfgang Pauli, and Werner Heisenberg to invent a new style of physical theory. As with the formalism of Bobby Alice, mature quantum theories in this tradition were abstract, offering probabilistic predictions for the outcomes of real-world measurements, while remaining agnostic about what it all meant, about what fundamental reality undergirded the description.

From the very beginning, a counter-tradition associated with names like Albert Einstein, Louis de Broglie, and Erwin Schrödinger insisted that quantum models must ultimately capture something (but probably not everything) about the real stuff moving around us. This tradition gave us visions of subatomic entities as lumps of matter vibrating in space, with the sorts of orbital visualizations one first sees in high school chemistry.

But once the various quantum ideas were codified and physicists realized that they worked remarkably well, most research efforts turned away from philosophical agonizing and toward applications. The second generation of quantum theorists, unburdened by revolutionary angst, replaced every part of classical physics with a quantum version. As Max Planck famously wrote, "A new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die." Since this inherited framework works well enough to get new researchers started, the question of *what it all means* is usually left alone.

Of course, this question is exactly what most non-experts want answered. For past generations, books with titles like *The Tao of Physics* and *Quantum Reality* met this demand, with discussions that wildly mixed conventions of scientific reportage with wisdom literature. Even once quantum theories themselves became familiar, interpretations of them were still new enough to be exciting.

Today, even this thrill is gone. We are now in the part of the story where no one can remember what it was like not to have the blinking lights on the ceiling. Despite the origins of quantum theory as an empirical framework—a container flexible enough to wrap around whatever surprises experiments might uncover—its success has led today's theorists to regard it as fundamental, a base upon which further speculations might be built.

Regaining that old feeling of disorientation now requires some extra steps.

As interlopers in an ongoing turf war, modern explainers of quantum theory must reckon both with arguments like Niels Bohr's, which emphasize the theory's limits on knowledge, and with criticisms like Albert Einstein's, which demand that the theory represent the real world. Sean Carroll's *Something Deeply Hidden* pitches itself to both camps. The title stems from an Einstein anecdote. As "a child of four or five years," Einstein was fascinated by his father's compass. He concluded, "Something deeply hidden had to be behind things." Carroll agrees with this, but argues that the world at its roots *is* quantum. We only need courage to apply that old Einsteinian realism to our quantum universe.

Carroll is a prolific popularizer—alongside his books, his blog, and his Twitter account, he has also recorded three courses of lectures for general audiences, and for the last year has released a weekly podcast. His new book is appealingly didactic, providing a sustained defense of the Many Worlds interpretation of quantum mechanics, first offered by Hugh Everett III as a graduate student in the 1950s. Carroll maintains that Many Worlds *is just quantum mechanics*, and he works hard to convince us that supporters aren't merely perverse. In the early days of electrical research, followers of James Clerk Maxwell were called Maxwellians, but today all physicists are Maxwellians. If Carroll's project pans out, someday we'll all be Everettians.

Standard applications of quantum theory follow a standard logic. A physical system is prepared in some initial condition, and modeled using a mathematical representation called a "wave function." Then the system changes in time, and these changes, governed by the Schrödinger equation, are tracked in the system's wave function. But when we interpret the wave function in order to generate a prediction of what we will observe, we get only *probabilities* of possible experimental outcomes.

Carroll insists that this quantum recipe isn't good enough. It may be sufficient if we care only to predict the likelihood of various outcomes for a given experiment, but it gives us no sense of what the world is like. "Quantum mechanics, in the form in which it is currently presented in physics textbooks," he writes, "represents an oracle, not a true understanding."

Most of the quantum mysteries live in the process of measurement. Questions of exactly how measurements force determinate outcomes, and of exactly what we sweep under the rug with that bland word "measurement," are known collectively in quantum lore as the "measurement problem." Quantum interpretations are distinguished by how they solve this problem. Usually, solutions involve rejecting some key element of common belief. In the Many Worlds interpretation, the key belief we are asked to reject is that of one single world, with one single future.

The version of the Many Worlds solution given to us in *Something Deeply Hidden* sidesteps the history of the theory in favor of a logical reconstruction. What Carroll enunciates here is something like a quantum minimalism: "There is *only one wave function*, which describes the entire system we care about, all the way up to the 'wave function of the universe' if we're talking about the whole shebang."

Putting this another way, Carroll is a *realist* about the quantum wave function, and suggests that this mathematical object simply *is* the deep-down thing, while everything else, from particles to planets to people, are merely its downstream effects. (Sorry, people!) The world of our experience, in this picture, is just a tiny sliver of the real one, where all possible outcomes—all outcomes for which the usual quantum recipe assigns a non-zero probability—continue to exist, buried somewhere out of view in the universal wave function. Hence the "Many Worlds" moniker. What we experience as a single world, chock-full of foreclosed opportunities, Many Worlders understand as but one swirl of mist foaming off an ever-breaking wave.

The position of Many Worlds may not yet be common, but neither is it new. Carroll, for his part, is familiar enough with it to be blasé, presenting it in the breezy tone of a man with all the answers. The virtue of his presentation is that whether or not you agree with him, he gives you plenty to consider, including expert glosses on ongoing debates in cosmology and field theory. But *Something Deeply Hidden* still fails where it matters. "If we train ourselves to discard our classical prejudices, and take the lessons of quantum mechanics at face value," Carroll writes near the end, "we may eventually learn how to extract our universe from the wave function."

But shouldn't it be the other way around? Why should we have to work so hard to "extract our universe from the wave function," when the wave function itself is an invention of physicists, not the inerrant revelation of some transcendental truth? Interpretations of quantum theory live or die on how well they are able to explain its success, and the most damning criticism of the Many Worlds interpretation is that it's hard to see how it improves on the standard idea that probabilities in quantum theory are just a way to quantify our expectations about various measurement outcomes.

Carroll argues that, in Many Worlds, probabilities arise from *self-locating uncertainty*: "You know everything there is to know about the universe, except where you are within it." During a measurement, "a single world splits into two, and there are now two people where I used to be just one." "For a brief while, then, there are two copies of you, and those two copies are precisely identical. Each of them lives on a distinct branch of the wave function, but neither of them knows which one it is on." The job of the physicist is then to calculate the chance that he has ended up on one branch or another—which produces the probabilities of the various measurement outcomes.

If, alongside Carroll, you convince yourself that it is reasonable to suppose that these worlds exist outside our imaginations, you still might conclude, as he does, that "at the end of the day it doesn't really change how we should go through our lives." This conclusion comes in a chapter called "The Human Side," where Carroll also dismisses the possibility that humans might have a role in branching the wave function, or indeed that we have any ultimate agency: "While you might be personally unsure what choice you will eventually make, the outcome is encoded in your brain." These views are rewarmed arguments from his previous book, *The Big Picture*, which I reviewed in these pages ("Pop Goes the Physics," Spring 2017) and won't revisit here.

Although this book is unlikely to turn doubters of Many Worlds into converts, it is a credit to Carroll that he leaves one with the impression that the doctrine is probably *consistent*, whether or not it is true. But internal consistency has little power against an idea that feels unacceptable. For doctrines like Many Worlds, with key claims that are in principle unobservable, some of us will always want a way out.

Lee Smolin is one such seeker for whom Many Worlds realism—or "magical realism," as he likes to call it—is not real enough. In his new book, *Einstein's Unfinished Revolution*, Smolin assures us that "however weird the quantum world may be, it need not threaten anyone's belief in commonsense realism. It is possible to be a realist while living in the quantum universe." But if you expect "commonsense realism" by the end of his book, prepare for a surprise.

Smolin is less congenial than Carroll, with a brooding vision of his fellow scientists less as fellow travelers and more as members of an "orthodoxy of the unreal," as Smolin stirringly puts it. Smolin is best known for his role as doomsayer about string theory—his 2006 book *The Trouble with Physics* functioned as an entertaining jeremiad. But while his books all court drama and are never boring, that often comes at the expense of argumentative care.

Einstein's Unfinished Revolution can be summarized briefly. Smolin states early on that quantum theory is wrong: It gives probabilities for many and various measurement outcomes, whereas the world of our observation is solid and singular. Nevertheless, quantum theory can still teach us important lessons about nature. For instance, Smolin takes at face value the claim that entangled particles far apart in the universe can communicate information to each other instantaneously, unbounded by the speed of light. This ability of quantum entities to be correlated while separated in space is technically called "nonlocality," which Smolin enshrines as a fundamental principle. And while he takes inspiration from an existing nonlocal quantum theory, he rejects it for violating other favorite physical principles. Instead, he elects to redo physics from scratch, proposing partial theories that would allow his favored ideals to survive.

This is, of course, an insane act of hubris. But no red line separates the crackpot from the visionary in theoretical physics. Because Smolin presents himself as a man up against the status quo, his books are as much autobiography as popular science, with personality bleeding into intellectual commitments. Smolin's last popular book, *Time Reborn* (2013), showed him changing his mind about the nature of time after doing bedtime with his son. This time around, Smolin tells us in the preface about how he came to view the universe as nonlocal:

> I vividly recall that when I understood the proof of the theorem, I went outside in the warm afternoon and sat on the steps of the college library, stunned. I pulled out a notebook and immediately wrote a poem to a girl I had a crush on, in which I told her that

> each time we touched there were electrons in our hands which from then on would be entangled with each other. I no longer recall who she was or what she made of my poem, or if I even showed it to her. But my obsession with penetrating the mystery of nonlocal entanglement, which began that day, has never since left me.

The book never seriously questions whether the arguments for nonlocality *should* convince us; Smolin's experience of conviction must stand in for our own. These personal detours are fascinating, but do little to convince skeptics.

Once you start turning the pages of *Einstein's Unfinished Revolution*, ideas fly by fast. First, Smolin gives us a tour of the quantum fundamentals—entanglement, nonlocality, and all that. Then he provides a thoughtful overview of solutions to the measurement problem, particularly those of David Bohm, whose complex legacy he lingers over admiringly. But by the end, Smolin abandons the plodding corporate truth of the scientist for the hope of a private perfection.

Many physicists have never heard of Bohm's theory, and some who have still conclude that it's worthless. Bohm attempted to salvage something like the old classical determinism, offering a way to understand measurement outcomes as caused by the motion of particles, which in turn are guided by waves. This conceptual simplicity comes at the cost of brazen nonlocality, and an explicit dualism of particles and waves. Einstein called the theory a "physical fairy-tale for children"; Robert Oppenheimer declared about Bohm that "we must agree to ignore him."

Bohm's theory is important to Smolin mainly as a prototype, to demonstrate that it's possible to situate quantum mechanics within a single world—unlike Many Worlds, which Smolin seems to dislike less for physical than for ethical reasons: "It seems to me that the Many Worlds Interpretation offers a profound challenge to our moral thinking because it erases the distinction between the possible and the actual." In his survey, Smolin sniffs each interpretation as he passes it, looking for a whiff of the *real* quantum story, which will preserve our single universe while also maintaining the virtues of all the partial successes.

When Smolin finally explains his own idiosyncratic efforts, his methods—at least in the version he has dramatized here—resemble some wild descendant of Cartesian rationalism. From his survey, Smolin lists the principles he would expect from an acceptable alternative to quantum theory. He then reports back to us on the incomplete models he has found that will support these principles.

Smolin's tour leads us all over the place, from a review of Leibniz's

Monadology ("shockingly modern"), to a new law of physics he proposes (the "principle of precedence"), to a solution to the measurement problem involving nonlocal interactions among all similar systems everywhere in the universe. Smolin concludes with the grand claim that "the universe consists of nothing but views of itself, each from an event in its history." Fine. Maybe there's more to these ideas than a casual reader might glean, but after a few pages of sentences like, "An event is something that happens," hope wanes.

For all their differences, Carroll and Smolin similarly insist that, once the basic rules governing quantum systems are properly understood, the rest should fall into place. "Once we understand what's going on for two particles, the generalization to 10^{88} particles is just math," Carroll assures us. Smolin is far less certain that physics is on the right track, but he, too, believes that progress will come with theoretical breakthroughs. "I have no better answer than to face the blank notebook," Smolin writes. This was the path of Bohr, Einstein, Bohm and others. "Ask yourself which of the fundamental principles of the present canon must survive the coming revolution. That's the first page. Then turn again to a blank page and start thinking."

Physicists are always tempted to suppose that successful predictions prove that a theory describes how the world really is. And why not? Denying that quantum theory captures something essential about the character of those entities outside our heads that we label with words like "atoms" and "molecules" and "photons" seems far more perverse, as an interpretive strategy, than any of the mainstream interpretations we've already discussed. Yet one can admit that *something* is captured by quantum theory without jumping immediately to the assertion that *everything* must flow from it. An invented language doesn't need to be universal to be useful, and it's smart to keep on honing tools for thinking that have historically worked well.

As an old mentor of mine, John P. Ralston, wrote in his book *How to Understand Quantum Mechanics*, "We don't know what nature is, and it is not clear whether quantum theory fully describes it. However, *it's not the worst thing. It has not failed yet.*" This seems like the right attitude to take. Quantum theory is a fabulously rich subject, but the fact that it has not failed yet does not allow us to generalize its results indefinitely.

There is value in the exercises that Carroll and Smolin perform, in their attempts to imagine principled and orderly universes, to see just how far one can get with a straitjacketed imagination. But by assuming that everything is captured by the current version of quantum theory, Carroll risks credulity, foreclosing genuinely new possibilities. And by assuming that everything is up for grabs, Smolin risks paranoia, ignoring what is already understood.

Perhaps the agnostics among us are right to settle in as permanent occupants of Reality Industries' fourth floor. We can accept that scientists have a role in creating stories that make sense, while also appreciating the possibility that the world might not be made of these stories. To the big, unresolved questions—questions about where randomness enters in the measurement process, or about how much of the world our physical theories might capture—we can offer only a laconic *who knows?* The world is filled with flashing lights, and we should try to find some order in them. Scientific success often involves inventing a language that makes the strange sensible, warping intuitions along the way. And while this process has allowed us to make progress, we should never let our intuitions get so strong that we stop scanning the ceiling for unexpected dazzlements.

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