Spencer Klavan's Light of the Mind, Light of the World.

CHAPTER 7

The Tower of Babel

It was all very well as long as we were allowed to treat the "primary qualities," as they called them—extension, solidity, figure, and motion—as included in inferred nature. But when these began to go the way of the secondary qualities; when even solidity turned into a secondary quality, it was bothersome. —Owen Barfield, Worlds Apart: A Dialogue of the 1960s

All the greatest minds in physics could see by now that a tectonic shift was underway. They met to discuss it in the fall of 1927, during the hush of peace between the world wars. There they were in their prime, each straining like a hunting dog after a prize buck, snapping at the heels of some new breakthrough that would make sense of the quantum. There was Einstein, the electrician's son, leery of authority and ill at ease in the high society that had scoffed at him not many years before. There was Prince de Broglie, the French aristocrat of Italian extraction, youngest scion of a dynasty whose origins stretched back into the glamorous medieval past. There was Niels Bohr, the soft-spoken philosopher; Paul Ehrenfest, the boisterous New Zealand rugby lad; Erwin Schrödinger, the passionate maverick; and Hendrik Lorentz, the beloved elder statesman.

They were there to bring order back into the universe. It was a matter of urgency. World War I had shown just how fearsomely consequential real scientific understanding could be—how it could give and take life, how the balance of world power could hang upon its management or mismanagement. The steel that tore across miles of train track could just as soon be sent ripping from a Mauser rifle into human flesh. Einstein's fellow German, the chemist Fritz Haber, had pulled nitrogen straight from the air to fertilize vast fields of crops and feed masses of hungry men and women. He had also concocted the chlorine gas that descended like a curse over the trenches and sent young men writhing to their graves, choking on blood and sputum.

Einstein's loathing of the war effort had kept him at arm's length from his countrymen for years. But as the horrors of those days faded into memory, he and his fellow scientists could tentatively aspire to work on gentler endeavors. They came together across the primly manicured lawns of Leopold Park outside the center of Brussels, near the still water of a manmade pond. It was quiet now in the city, and the leading lights of the troubled modern world could hope for peace. But they could not agree.

Just as Europe's glimmering civilization had collapsed inward upon itself in a savage bloodletting, so now the elaborate architecture of scientific knowledge, carefully built up brick by brick since the days of Galileo, tottered and threatened to cave in. The mathematical equations of physics, which had seemed to trace in outline the very foundation stones of reality, were now delivering results that no one could satisfyingly interpret or understand. Not only could waves of energy harden into mass, but particles of mass could melt into patterns of energy. The orderly world picture of classical physics had begun to shift and bend into something unrecognizable.

At the end of the 1927 conference, Paul Ehrenfest, one of the world's greatest mathematicians, walked to the blackboard and wrote down a passage from the Book of Genesis: "And the Lord said: Go to, let us go down, and there confound their language, that they may not understand one another's speech." 3 It was supposed to be a primitive legend from the distant past: the Tower of Babel, humanity's misbegotten effort to make a name for itself. A jealous God, said the story, had descended to turn the builders' surefooted ascent into a chaos of confusion and disarray. But physics was not supposed to be vulnerable to this kind of supernatural interference. It was supposed to be a sure and rational picture of the world, as exact as it was tangibly real. This tower could not be shaken: its foundation was in the solid rock of the earth, and its spires reached up in graceful aspiration toward the highest heavens. Yet here were its most skilled architects, and they were as mutually unintelligible to one another as if some vengeful deity had scrambled their speech.

The Dissolving World

The problems came down to the most basic interpretations of the new physics. If a particle can be a wave, what is it a wave of? What medium is it moving through? In the Christmas and New Year's season of 1925–1926, Schrödinger gave mathematical form to the waves in question. Absconding dramatically to a Swiss villa with one of his several mistresses and a copy of de Broglie's PhD thesis, stuffing a single pearl in each ear to drown out the noise around him as he worked, the mathematician rummaged in the dark heart of a strange new world. The result was six papers outlining the mathematical rules governing quantum waves.4 Schrödinger's wave function, for which he won the Nobel Prize, is an operation that describes a set of "standing waves"—waves that form a set pattern, rather like a guitar string vibrating up and down. Schrödinger equations can produce values for the total energy of any subatomic particle, tracing its contours to describe a permanent wrinkle in the bedrock of existence. They have proven as fundamental to quantum physics as Newton's relationship between mass and acceleration is to classical systems. Schrödinger had developed an outline of the waves that doubled as the smallest known particles. But he had nothing to say just yet about what those waves were moving through.

It was the German physicist Max Born who proposed an answer: Schrödinger waves describe the probability of finding a given particle in a particular place, or possessing a particular momentum, under given conditions. Solutions to the wave function indicate how likely it is that a particle will be found at any point in space. The same goes for the particle's momentum: the equations predict which values are likely to emerge if it is measured—but none that are certain to emerge. The wave function is, in Schrödinger's words, "the means for predicting probability of measurement results."

This was a monumental achievement. It was also a disaster. The entire edifice of physics—the whole Tower of Babel—rested on the faith that numbers could describe objects in themselves as they are, liberated from any error or ambiguity of human judgment. Philosophy, Galileo had written in the seventeenth century, "is written in the language of mathematics." 6 That language was supposed to be pristinely exact, parsing the joints and outlines of reality like a razor blade.

If a given star was a sphere of a million kilometers in diameter, it would remain that way even in daylight: though it may disappear from sight, its contours would stay firmly in place. To a human onlooker from earth it might glimmer or fade with the passing of night, curving in its arc across the sky. But in truth, in the regions untouched by any sense perception, the star of the heavens was no flickering pinpoint. That was only its transient effect upon the human eye, the outline it had first cast upon the confused screen of an upright ape's clouded mind. Men had risen beyond those muddled origins now to grasp the truth of things: a star was an object like any other, described by its measurable quantities, hanging firm in the space allotted to it by its geometric outlines. The thing in itself corresponded exactly and directly to the numbers that described it.

Among those numbers, the atom was supposed to be the simplest unit. It was the alphabet of the mathematical language. That is why so much rested on the particle, the small god moving rationally and eternally, enduring undisturbed beneath even the most violent change. As the component parts of the atom came into view, protons and neutrons were assigned a weight of one "atomic unit" each, as if to fix them as the basic unity that made counting things possible, the number out of which all other numbers are built.

Existence was supposed to be made by tallying up these numbered objects, each interchangeable with others of its type like tokens or tallies, corresponding in both mathematics and experiment to fixed measurements. Here was a hydrogen atom, with one proton and one electron. Here was helium, with two each of protons, neutrons, and electrons. Like the stars, they were set in their courses, positioned exactly in space—their quantities, once known, could explain all other movements and positions. Maxwell had called them "the foundation stones of the material universe."

And yet now, at the tantalizing moment of discovery, right at the threshold of the atomic realm, the solid particles of matter dissolved into mere possibility and potential. They did not, after all, occupy just one point in space, unless a measurement of their position was taken. When no one was looking, they were not definitely in any one place: there was only a range of more and less likely places, a wave of options shivering through a sea of likelihoods. But options and likelihoods are not objects; any wave that travels through them is not made of matter. It was as if the solid ground had fallen away with a lurch and left humanity suspended in midair. The world beyond the edges of sight had begun to dissolve.

A Terrifying Relentlessness

In May 1925, on the spare and cliff-bound Danish island of Heligoland, a vigorous young member of Max Born's faculty invented a strange new mathematics that could keep pace with the disjointed movements of subatomic particles. His name was Werner Heisenberg, and his system was a form of matrix algebra—grids of numbers stacked and interlocked with one another. Unlike other atomic theorists, Heisenberg made no attempt to picture what his numbers described: it couldn't possibly be pictured. The quantum behavior of the atom, when it wasn't being measured, defied every category and boundary of human experience. Heisenberg's idea couldn't be visualized, couldn't be sculpted out of clay or bronze like some ancient model of the solar system or Dalton's wooden models of the atom. Heisenberg's mathematics was simply an array of relationships that predicted what would be seen when a human experimenter made measurements. And it worked.

The discovery left Heisenberg lightheaded, as if he was peering past the outlines of the material world into a deep underground of pure ideas: "I had the feeling that, through the surface of atomic phenomena, I was looking at a strangely beautiful interior, and felt almost giddy." 8 Sleepless, he clambered his way to a spur of rock jutting over the coast. Before his eyes, the sun rose as it always had over the cold sea. But beyond his vision—outside the range of any human sight, in the unseen world excluded from sense perception—a far more alien landscape was taking shape. There, in those new regions beyond the boundaries of what any human could see or imagine, the particles of nature burst the constraints of physical embodiment and performed unimaginable feats.

Heisenberg's mathematical latticework mapped neatly onto the heady theories of Niels Bohr, a young Dane whose hulking stature masked a gentle, soulful demeanor and an eerie habit of gazing into the clouded regions where scientific observation met philosophical speculation. Bohr worked out the steps of an energetic dance between protons and electrons, identifying the positions that electrons could occupy around the nucleus of an atom where the balance of charges would remain stable. An electron that took on energy—by being heated, for example—would flit to a new region where it could keep from surging out of control or collapsing inward to collide with the nucleus. But—and here was the inconceivable thing, the spectacular event that simply defied visualization—an electron that took on enough energy would slip from one place to another without occupying any of the locations in between. One moment it was here, the next it was there. When it fell back into its original place it would again skip nimbly over the intervening space, casting forth a burst of light in the form of Einstein's massless photons.

All this frustrated the most basic intuitions of scientists and laymen alike. If anything was obviously true of physical objects, it was that they traveled from one point to another across an unbroken line of motion, touching every point along the way. They did so whether or not anyone was watching; they were not supposed to change the rules when mankind's back was turned. Yet here at the most basic level, particles seemed to jump from place to place or even hover in a range of various possible locations. The picture of the world was becoming pixelated, chunked up into tiny regions of mystery where nothing could be nailed down. Planck's constant set an impenetrable barrier around the smallest areas of space, making it impossible for the mind to picture what went on within them. In those forbidden realms, the particles that had once seemed like solid objects scrambled every natural idea of the physical world, moving and changing in ways the mind simply could not envision. Beyond a certain limit, everything went dark.

According to Bohr, this was entirely to be expected. His explanation was devastating in its simplicity: what can never be seen, can never be visualized. The unobserved behavior of particles can, of course, never be described in terms of human observation. Concepts like "location" and "motion" are not in the end purely numerical facts, independent of human experience. They are descriptions of how humans can perceive and measure the outside world. Particles exist outside of us, but all the terms we use to describe them—even the mathematical ones—refer to our experience of them.

Quietly but doggedly, Bohr insisted on stripping down particle physics to a description of how the outside world was likely to affect human observers. "However far the phenomena transcend the scope of classical physical explanation, the account of all evidence must be expressed in classical terms," he argued. Heisenberg's mathematics, Schrödinger's probability waves, Einstein's photons, and Bohr's own electron orbits were all impossible to picture, because what they described could never be experienced. The outside world was real, and facts about it could be known. But they would always be known through observation and measurement, filtered through the shapes and forms of a conscious mind.

Quantum mathematics gave information about how a man could experience a single particle once he measured it. But as for what was happening to the particle when no man was looking—it could not even be spoken of. Particles were not "in many places at once" when described by the Schrödinger wave; they were not in any particular place, because no one was experiencing their location. What's more, Heisenberg's equations showed that experiencing their location put an inherent limit on knowledge of their momentum, a so-called "uncertainty principle" that set bounds to which physical properties could be resolved from potential to reality at any given time.

The idea appalled Einstein and unnerved Schrödinger, both of whom came up with one thought experiment after another to try and prove that something outside the realm of human experience could be known. When they met at conferences, they haggled over these puzzles for hours, late into the night, searching for a way around Bohr's obstacles—but to no avail. Heisenberg remembered the unyielding intensity with which Bohr defended the boundaries of human knowledge: "for though Bohr was an unusually considerate and obliging person, he was able in such a discussion, which concerned epistemological problems that he considered to be of vital importance, to insist fanatically and with almost terrifying relentlessness on complete clarity in all arguments. He would not give up, even after hours of struggling."

Destroyer of Worlds

Bohr and his collaborators were used to pressing beyond the farthest frontiers of what was known about the world. But now Bohr was forcing them up against the limits of what could conceivably be known, the hard barrier of the mind itself.13 Beyond the borderland of human experience, where no measurement could be taken and no observations made, the normal framework of space and time simply ceased to apply. When subatomic particles did slip back into view—when they made an impact on the world of human perception through a measuring device—they bore clear marks of having behaved in ways that could not and would not make sense to picture.

The mind is like a sheet of fabric with images of space and time sewn onto it in needlepoint: when they pierce into the domain of human experience, atoms and particles resolve themselves into neat objects traveling in continuous lines. But underneath the canvas, the picture collapses into a tangle of shifting threads. Out in the wilds of the unseen realm, isolated particles cease to be particles altogether in any meaningful sense of the term; they lose all definite sense of place and billow outward into a cloud of possible locations.

Send a single electron or photon traveling through a narrow slit in a barrier, then through two more slits on the other side: it will not pass neatly through in a straight-line trajectory. Instead it will scatter into one of several regions predicted by Schrödinger's wave function, as if its many possible trajectories had gone on lapping against each other until they crashed and broke against the rock of the visible world.

Or shoot a photon at a device called a "silvered mirror," which has a fifty-fifty chance either of letting the light pass through or of reflecting it onto a different path. Then set up regular mirrors in the way of both possible trajectories, bringing the potential paths back together at a final silvered mirror. The one photon will then behave as if it has taken both roads at once, "colliding with itself" at the last mirror and ending back up on a single course.

Or, more confoundingly, subject an electron to the influence of a magnet and it will exhibit behavior that can only suggest it is making two rotations in one, spinning twice rather than once before it ends up for the first time back at its original angle—a meaningless statement, impossible to visualize.The words themselves for describing motion and shape break down; what cannot be perceived cannot be stated in terms of human perception. Quantum equations don't describe the outlines of a world we can see and touch: they describe the limits where things cease to become tangible or visible. The world beyond those limits is not made of solid objects.

Yet it is real. Any teacher in your average American high school will point out areas on the board using a LASER (Light Amplification by Stimulated Emission of Radiation), a device which creates a cascade of photons pouring forth in a narrow beam from the precise transition of electrons between energy states. These quantized glimmers can be honed to pinpoint accuracy and shot in coded patterns along the fibers of a modern internet cable, a flicker of information whipping across space in the form of light. Computers may soon wildly outstrip their current speeds using quantum bits (“qubits”), which can register not only ones and zeros but both also a simultaneous blend of the two, occupying a “superposition” of two binary states at once.

And of course, the world’s first quantum physicists received devastating confirmation of their own theories when, to the mixed horror and amazement of a watching world, two clouds of wreckage hovered over Japan and brought an end to World War II. Firing neutrons at the core of uranium and plutonium atoms, the scientists of the Manhattan Project built the world’s first atomic bombs by sending the bolts and rivets of the universe skittering apart. The grains of the world came tumbling through the crevices of space, as atoms at last gave up the bonds that made them whole in a thunderous blast of energy and became death, destroyer of worlds.

The Reappearance of Things

It was not just cities that the quantum revolution wiped away into nothing. An entire picture of the world was being erased: the picture of the mechanical universe, with its solid moving parts churning on unseen, was beginning to fade and dissolve. For some of the twentieth century’s greatest thinkers, this prospect was too much to bear. Einstein refused to countenance what he called the “ghost waves” and “dice games” of quantum mechanics: somewhere underlying all of it there must be a solid mathematical picture, “a theory which describes exhaustively physical reality, including four-dimensional space,” whether observed by a human onlooker or not.

Yet it was becoming clear to everyone, as Schrödinger put it in 1931, that “the mathematical apparatus derived by Newton is inadequately adapted to nature.” At Bohr’s relentless prompting, the pioneers of quantum physics were forced to grapple with the possibility that their discoveries might—in the words of Schrödinger’s translator and interviewer James Murphy—“reduce the last building stones of the universe to something like a spiritual throb that comes as near as possible to our concept of pure thought.” Bodies in motion were not the heart of things: they arose out of a darker and more mysterious well, resolving before human eyes into the familiar shapes described by geometry. Perhaps it was only when they could be seen by a conscious observer that “objects” made any sense at all.

This was an ancient truth. It had been hinted at in scripture and wisdom literature all along. But it also represented the end of a centuries-long quest. The scientific revolution had begun in the hope of going beyond appearances, puncturing the fantasies of the human mind and seeing things as they “really are.” Galileo and Descartes had aspired to gaze past all the merely subjective qualities of the material world, peeling away color and texture and sound until only the raw mathematical facts of position, size, and location were left. But now it is becoming clear that even those supposedly pristine numerical attributes are partly indebted to human perception. They are not arbitrary: any two healthy observers can match up their experiences and agree on the location of a tree or a house. But even concepts like “location” can only accurately be used to describe the smallest objects once someone is there to do the describing.

It could never have been otherwise. From the beginning, mathematics was only ever designed to “save the appearances.” It was an abstraction derived from and about human experience, created to explain and apply to human experience. The most optimistic impresarios of the scientific revolution made more daring promises on behalf of numbers, claiming that they could trap the universe in amber and freeze the world into a perfect interlocking mechanism of material objects. But the world is not made only of material objects. It is made of the meeting between mind and matter. It is this human encounter with the outside world that brings it shimmering into an array of form, color, and light.

The human mind—that supposedly primitive and dispensable screen of illusions—is far more fundamental than was once assumed.20 It is not an obstacle, throwing up its dreamlike fancies of selfhood and spirit into the way of hard numerical truth. It is a vehicle, bringing the potential of the unformed material world into definite reality. Things are not divided into “primary” and “secondary” qualities, split between the hard facts of matter and the vaporous deceit of human experience. Human experience is part of the world, which is built up from the raw potential of existence into the panoply of color and light that passes before our eyes. The reign of the small gods is over, and their Tower of Babel is fallen. We are left at the center of the universe, helping to grant it life.

Klavan, Spencer A.. Light of the Mind, Light of the World. (pp. 147-160). Skyhorse Publishing. Kindle Edition.