The QUANTUM TEN

A STORY *of* PASSION TRAGEDY, AMBITION AND SCIENCE

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Chapter One

THE REGRESSION OF SCIENCE

Science . . . is part and parcel of our knowledge and obscures our insight only when it holds that the understanding given by it is the only kind there is.

CARL JUNG

Theoretical physics is in trouble. At least that's the impression you'd get from reading a spate of recent books on the continued failure of the reigning star of theoretical physics—superstring theory—to resolve the eighty-year-old problem of unifying the classical and quantum worlds.

Over the past three decades, a whole superstring industry in academia has grown out of the attempts by theoretical physicists to capture the elusive Holy Grail of physics by, at long last, coming up with a way of integrating the two completely incompatible sets of physics rules for our universe. There are careers and reputations at stake, not just for the leading string theorists and their entourages of post-docs and graduate students, but also for physics departments that have channelled much of their funding and talent into strings.

It's not surprising, then, that a growing unease in the physics community about the validity of string theory as a viable research enterprise is turning into a rather testy exchange between those with a vested interest in keeping it going and those who think it's an idea that has run its course—and consumed quite enough of the limited funding available for theoretical research. The issue is being debated in science journals and in the mainstream media, as well as in online physics forums and blogs. At times, the level of discussion between defenders of string theory and its challengers has descended to a decidedly childish and even offensive level. When some scientists feel their careers and favoured ideas are threatened, the need to defend and protect their interests can far outweigh the romantic ideal of scientific research as a pursuit of truth, unsullied by human emotion and personal agendas.

This kind of angry and defensive push-pull in scientific inquiry is nothing new. The same thing happened eight decades ago during the creation of quantum physics. That's when a set of physics rules was established for the quantum or microscopic world, but it was a set of rules that was completely incompatible with the existing set for the classical or macroscopic world. Albert Einstein objected to the rules for quantum physics while they were being developed precisely because they appeared to preclude any means of reconciliation with the classical rules upon which his generalized theory of relativity was based. String theorists are still trying to finish what Einstein started eighty years ago, and with about as much success as Einstein had.

If, after such a long time, all the smart men and all the smart women who work in physics have not been able to reconcile the two sets of rules for the universe, it's natural to wonder if one—or both—of the sets might just be wrong. But suggesting that either of the two most successful, experimentally verified models of physics might be wrong is tantamount to goring a sacred cow. Just as questioning the validity of string theory can raise the hackles of its supporters, so can questioning relativity or quantum physics.

A discomfort with the strange and seemingly inexplicable properties of the quantum has been bubbling under the surface of quantum physics since its creation. And at times the discomfort has boiled over into heated debate between physicists over whether there's something fundamentally wrong with quantum physics or whether it's just fine the way it is. Indeed, there have been more than a few public yelling matches between leading physicists, shouting at each other across conference rooms, about whether it's time to revisit the development of quantum physics and see if, just maybe, there is another way of looking at the quantum world.

Perhaps it *is* time, particularly in light of an emerging ideological trend in string theory. The key weakness of string theory is that it is not experimentally verifiable or falsifiable—although some of its leading proponents will posit that it could be tested if, for instance, we could build a particle accelerator the size of the Milky Way Galaxy[1]—and, being untestable, string theory can be considered a highly elaborate mathematical exercise. Physicist and string theory popularizer Brian Greene has admitted that unless string theory can make predictions that are subject to experimental verification, "it will be no more relevant than an elaborate game of Dungeons and Dragons."[2] Since it's highly unlikely humans are ever going to build a galactic-scale particle accelerator, a few of the world's leading physicists have begun toying with the idea that the problem of string theory's non-testability might be eliminated by dropping experimental testing as a condition for determining the validity of the string proposal.

It may seem rather bizarre to propose that research in physics could be advanced by dropping the actual physical testing, but it's not a new idea. In the world of the ancient philosophers, rational and logical thinking was all that was required to understand the physical world; to conduct experiments was to sully the art of pure intellectual reasoning. That particular viewpoint served to stall scientific progress for about two thousand years. For the past five centuries, however, scientific progress has flourished with the help of experimental verification.

It used to be that modern physics, the most fundamental of sciences, progressed by a quite workable marriage of philosophical theory, mathematically based physics rules and experimentation. When Einstein began working on his theory of general relativity, he started with a thought experiment and a hypothesis. He imagined that gravity was actually the effect of mass curving space and curving the path of light as well. He could visualize it. Einstein then set about finding the mathematics with which to calculate the curvature. He wasn't very good at math, so he relied on a couple of friends who were also physicists to give him a hand. By 1917 they had worked out all the kinks in the math, but it wasn't until the solar eclipse of 1919 that Sir Arthur Eddington and his crew gathered the supporting evidence for Einstein's hypothesis. Eddington and others were able to show that light from stars was indeed caused to curve as it passed by the huge gravitational mass of the sun.

The process Einstein followed is one quite familiar to high school or fifth form science students. He used a long-standing method of conducting science: form a hypothesis that predicts nature will behave a certain way, find an equation suitable for making predictions, and then conduct experiments to validate or falsify the hypothesis. Once Einstein's prediction that mass curved space was borne out by experimental validation, his hypothesis became a theory.

But not long after Einstein's high-profile success with general relativity—it had made him a world celebrity—the scientific method began to change. The cause? The discovery of a strange new atomic realm with bizarre rules that were impossible to visualize.

The quantum world of the atom operates by rules that are physically impossible in our everyday world. It's a very strange notion that everything in the ordinary world is made up of "quantum stuff," such as electrons, light waves and atoms, and yet there is no way to make the macroscopic and microscopic worlds operate under a single set of rules. Despite the best efforts of some of the greatest scientific thinkers of the time, the quantum revolution of the mid-1920s failed to produce a philosophical world view capable of combining the two disparate worlds into one sensible theory. If anything, the scientists who developed quantum physics created the very unification problem that string theorists are still trying to resolve.

At this point, it's worth adding some clarity to the terms physicists use to talk about quantum science. They often treat the phrases "quantum mechanics," "quantum theory" and "quantum physics" as if they were interchangeable, which they are not. Throughout this book, "quantum mechanics" is defined as the set of rules for *how* the physics and mathematics are used to make testable predictions; these rules have been used to unparalleled fruitfulness since their development in the 1920s. "Quantum theory" is defined as the explanation for *why* the quantum world behaves the way it does; this exercise is still fraught with controversy. "Quantum physics" is the whole package—the mechanics and the theory.

By the 1930s, most physicists simply abandoned the need for a philosophical theory of quantum physics, mainly because no one had been able to come up with an explanation that made any kind of sense of the strange quantum world. The rush of discoveries using just the mathematics-based quantum mechanics and experimental testing produced new fundamental laws to explain atomic structure and identify the kinds of particles that make up the universe—along with Nobel prizes for scientists at the forefront of discovery. What need for a unified, philosophical world view when the creative use of mathematics produced such marvellous results?

By the 1940s, not only was philosophy no longer considered a necessary part of science, it was seen as antithetical to science. (To this day, the ultimate put-down in physics is to call someone's work "philosophy.") Truth could be established using only mathematics and experiments, with the logic of mathematics driving discovery. This fit well with the dominant philosophy of the time, particularly the one advocated by the Vienna Circle which flourished in the 1920s and 1930s.

The goal of the European philosophers, scientists and mathematicians who made up the Vienna Circle was to develop a unified science where true knowledge, as they defined it, could be obtained from the evidence of the senses alone (what could be observed, counted or otherwise measured) and by the use of analytical logic, particularly the kind used in mathematics. There was no place for gods or metaphysics or any other kind of airy-fairy theories here. Indeed, the point of positivist philosophy was to create a world view "positively" free of metaphysics, mysticism and the supernatural, and to anchor knowledge and truth in something verifiable (via experimental testing) or logically consistent (mathematical). This philosophy was called *logical positivism*. The popular philosophical model promulgated by the Vienna Circle fit the math-driven quantum physics like a glove and helped to make the strange new science more palatable. However, the remarkable experimental success of quantum mechanics masked the empty place where a coherent theory should have been.

By the 1960s, the fruitfulness of the math-driven theory and experimentation began to wane. There have been no new fundamental laws of nature discovered since the 1970s, and there is still no math-driven theory that can reconcile the quantum and classical worlds.

The string theory posits that the universe is not made up of elementary particles such as electrons, quarks and neutrinos, but comprises incredibly small "strings" or tiny rips in the space-time continuum that operate in ten or eleven dimensions. Just try to visualize that! Theoretical physicists have also tried to unify classical gravity with the quantum world through a field of study called quantum gravity, but it too has foundered on the fact that gravity is so weak at the atomic level that it is outside the range of experimental testing.

Most math-driven theorists in physics have long since parted company with the experimentalists, so much so that there is now a whole generation of theoretical physicists who know nothing about how to design experiments to test their hypotheses—and, moreover, feel no need to know. Dutch Nobel laureate Gerard 't Hooft has recently argued that scientific progress can continue without experiments if theorists carefully apply rigorous logic. For instance, there is no possible way to test theories that involve the incredibly tiny atomic measurement called a Planck length.* This means, according to 't Hooft, "the only instrument we can use to study the Planck length in detail, is our minds." But 't Hooft is also mindful of how important it has been to be able to use experimental verification to distinguish between competing theories. "Unfortunately," he says, "history has also shown how easily we can be misled into wrong theories, and how important it was, throughout the ages, that we could ask Nature to settle our disputes."[3]

American Nobelist Steven Weinberg has suggested that this could mark a "heroic age when theorists cut themselves temporarily free from their experimental underpinnings" and make use of "pure theoretical reasoning to develop a unified theory of all the phenomena of nature."[4]

But isn't that how philosophers such as Pythagoras, Plato and Archimedes did science some 2,500 years ago? They placed no value on experiments, but rather relied on carefully thinking through ideas until they arrived at a logically consistent explanation for how the natural world worked. Pythagoras founded his own mathematics-based religion, seeking the divine principles governing the universe through pure thought and analytical reasoning. Plato, for his part, condemned the use of mechanical measuring devices in geometry because it reduced the "incorporeal and intellectual" art to a "vulgar handicraft." Archimedes did do some experimentation but nonetheless held that it was quite inappropriate for philosophers to make practical use of science in the mundane world.[5]

By limiting themselves to intellectual reasoning, the scientists of ancient times limited themselves to a single means of determining truth and reality. Their scientific method relied on a one-trick pony. It wasn't until experimentation became an accepted part of physics, beginning in the middle of the sixteenth century, that significant progress was made in science. The result was a dramatic shift in the practice of physics and the introduction of the Newtonian

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*A Planck length, named after German physicist Max Planck, is 1.6 x 10-35 metres.

world view. Isaac Newton combined philosophical theory and experiment, and where the necessary mathematics was missing, he invented it.* Thus was the triumvirate of theory, mathematics and experimentation established and put to good use for the next three centuries.

Mathematics is now so widely accepted as the arbiter of truth in the modern world that it has become the backbone of disciplines ranging from physics (of course) to economics and sociology. Backing up a statement with mathematics gives it an aura of validity, even if the topic has to do with something as mathematically messy as human behaviour. The popular CBS television series *Numb3rs* provides a good illustration of the Western world's belief in the power of mathematics. In each episode, two mathematical geniuses are brought in by the FBI to solve intractable cases. By using the magical power of complicated mathematics, they can predict everything from the location of a hostage to where a sniper will strike next. Like modern dragon slayers, the mathematicians always save the day . . . and the hostage.

Of course, *Numb3rs* is theatre. In the real world, predicting human behaviour is enormously complicated. Just ask the people who utilize math programs in an attempt to predict how people will vote or the next big thing on the stock market. Reading chicken entrails or going with a gut feeling can often be just as effective as attempting to crowbar human behaviour into a mathematical model.

The popularity of mathematics as a truth-teller lies primarily in the certainty it provides. Mathematics comes with proofs. A mathematician first devises a set of rules or axioms, and then uses a series of logical statements to arrive at a conclusion. If there are no flaws in the logic, the conclusion is proved. That's it. No messy testing is required.

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*Isaac Newton and Gottfried Leibniz are both credited with coming up with calculus in 1684, working independently. But Eastern mathematicians had been developing elements of calculus long before it became part of Western science.

There is, of course, nothing wrong with using logic as a means of arriving at an understanding of the natural world. But logic has its limits. In the sixth century BCE, the people of Elea in southern Italy were caught up in the intense excitement of logic as a new and novel method of reasoning. "Logic was the rage of the day; all over, in the marketplaces, in the streets, in private homes and public buildings, at all times, sometimes all through the night, people engaged in dialectic disputations and flocked to hear the acknowledged masters of logical argument display their art." It all got a bit out of hand, however. The appeal of logic as a means of constructing truth was so great that wherever an exercise in logic contradicted obvious physical evidence, the Eleatics happily conceded that logic prevailed and the evidence of their senses was hallucinatory.[6]

The Eleatics are credited with being the first to introduce logic into the search for truth about nature and reality, and they were also the first to demonstrate, in a classic case of *reductio ad absurdum*, the silliness that can follow when logic alone is the arbiter of truth.

Where the Eleatics would say logic is truth, modern physicists would say mathematical logic is truth. Indeed, no idea in modern physics can be considered credible until it is validated by mathematical logic. It would make no sense to float the idea of dropping experimentation as a means of determining truth unless you have profound faith in the power of mathematics. The danger of heading down this path is that modern theoretical physics—the science that explains our most fundamental reality—risks becoming once again a one-trick pony. It didn't work so well for the ancients, given that Aristotelian science stalled for a couple of millennia. Modern theoretical physics has been stalled for only a couple of decades, so maybe it's a bit early to panic. But some theoretical physicists and mathematicians are sounding the alarm bells about the direction theoretical physics is taking.[7]

It may seem quite bizarre that modern physics would seek progress by regressing to a pre-Newtonian form of scientific methodology, but perhaps the signs have been there all along—we just didn't recognize them.

The seeds of the shift currently taking place in science were sown eighty years ago, from 1925 to 1927. That's when a dramatic two-year revolution in physics reached a climax, and the dénouement set the course for what was to follow. It's the story of a rush to formalize quantum physics, the work of just a handful of men fired by ambition, philosophical conflicts and personal agendas.

This was never a team effort. Sometimes, two or three would collaborate for a while, but mostly they were rivals who wanted their particular version of the new science to prevail. They had little enough in common. They were German, Swiss, Austrian, French, Danish and English; from royal blood, academic dynasties and the working class; Lutheran, Jewish, Catholic, Vedantic and atheist. About all they had in common was the fact that they were white, European males. But each of them contributed to the quantum puzzle a crucial piece needed to formalize the new science, and each played a role in a quantum revolution that stalled in a pressure cooker of tension, tragedy and betrayal.

The development of quantum physics also coincided with the final glory days of a grand scientific dynasty in Germany. The Great War had dealt a heavy blow to German pride, and the humiliation of the Treaty of Versailles, which laid out the terms of German surrender, fuelled the desire to see science return to its former exalted status for the sake of the Fatherland. It also fuelled a rising nationalism that designated Jews and foreigners as scapegoats for Germany's failed expansionist ambitions.

Quantum physics was still very new in the 1920s. Max Planck is typically credited with introducing "quanta" into the lexicon of physics in 1900, and in 1905 Einstein quietly opened a can of worms by using quantization to demonstrate that light could be both a particle and a wave. But it wasn't until Niels Bohr, a young Danish physicist, applied quantization to the planetary model of the atom in 1913 that anyone was much interested in this "quantum" stuff.

It was a tricky start. Bohr's atomic model introduced the strange idea that electrons which orbited the nucleus of an atom could jump from one allowed orbit to another without traversing the space in between. It's like standing on one side of the room and then suddenly being on the other side, without ever crossing the floor. That type of behaviour is not allowed in the classical world, but it's what seemed to be happening in the atomic world. Some physicists were so offended by this violation of classical physics that they threatened to quit the profession if "quantum jumps" turned out to be true.

It quickly became apparent that the quantum world of atoms and electrons did not seem to be operating by the same rules of physics as the everyday, classical world. In classical physics, energy flowed continuously, but in quantum physics it came in chunks, or quanta. The quantum world allowed that light could be both a defined object and a spread-out motion at the same time, which simply could not happen in the classical world. And then there were quantum jumps to consider. It was getting harder and harder to see how the physics rules could ever be reconciled into a unified picture.

The Great War slowed scientific progress in Europe. Germany had been the undisputed world leader in physics at the onset of the war, and much of the scientific talent was put to work in the cause of the Fatherland, which didn't leave much time for theorizing about the strange new quantum world. By the end of the war Germany was in rough shape, but the science community got back to work rebuilding itself, and there was time to return to the puzzling new science that had just begun emerging in the pre-war years.

By the early 1920s, the quantum revolution was under way. It was obvious that classical physics could not explain the quantum world, but it was far from clear how much of the old science would have to be jettisoned in order to make way for the new. Nor was it clear how the strange impossibilities of the quantum world could ever be integrated into a theory that also included the classical world.

With the increasing reliance on symbolic mathematics to "describe" the quantum world, it was also getting harder and harder to visualize how the microscopic world operated. For some of the quantum revolutionaries, it wasn't necessary to be able to visualize the quantum world as long as their calculations matched experimental results. It didn't matter that the symbols and mathematics they used might not have any link to physical reality; mathematical "truth" was enough. But for others, not being able to create a mental picture of the quantum world, in the same way that Einstein had imagined curved space-time in his classical theory of general relativity, meant the quantum world would be forever out of reach.

This was the problem facing the physicists at the forefront of the revolution. In the years from 1925 to 1927, they were hammering out a mathematically logical physics to describe how the quantum world operated (quantum mechanics) and struggling to come up with a sensible explanation for why the quantum world behaved as it did (quantum theory). They succeeded at one but fumbled the other.

Remarkably, this dramatic shift in science was primarily the work of ten men, and they were ten very fallible men, some famous and some not so famous, although they also had a large supporting cast. Their triumphs and tragedies, loves and betrayals, dreams realized and ambitions thwarted, shaped the competition over who would get to define truth and reality. There never was a consensus. By the time of the pivotal Fifth Solvay Conference in Brussels in 1927, there was so much ill will and disappointment among the creators of quantum physics over their various competing theories and over who deserved credit that most were barely on speaking terms.

The Brussels conference was the first time so many of them had come together: Albert Einstein, the lone wolf; Niels Bohr, the obsessive but gentlemanly father figure; Max Born, the anxious hypochondriac; Werner Heisenberg, the intensely ambitious one; Wolfgang Pauli, the sharp-tongued critic with a dark side; Paul

Dirac, the quiet one; Erwin Schrödinger, the enthusiastic womanizer; Prince Louis de Broglie, the French aristocrat; and Paul Ehrenfest, who was witness to it all. Their coming together, however, lasted only for the duration of the conference.

The Solvay conferences, which had begun in 1911, were funded by the wealthy Belgian industrialist Ernest Solvay, and were not at all like modern science conferences. Today's conferences are marathons of multiple simultaneous presentations by scientists with perhaps twenty minutes to speak, typically preceded by harried fumbling to get the PowerPoint presentation up and running, followed by five minutes of questions from the audience. The Solvay conferences instead focused on a handful of talks by eminent scientists, followed by lengthy discussions and debates in which everyone present had the opportunity to speak and be heard. The whole point of the conferences was to thoroughly explore some aspect of cutting-edge physics, giving the specialists in that area a chance to make a case for their preferred theories and the other notables the opportunity to offer, ideally, thoughtful and constructive criticism. They were by-invitation-only affairs, gatherings of the who's who of world physics in the particular area under discussion, with meetings taking place every three years (unless there was a world war going on).

The attendees of the Fifth Solvay Conference boasted seven Nobel prizes in physics (eight if two-time winner Marie Curie's Nobel for chemistry is included), and of the twenty-nine scientists in attendance, another nine would later receive Nobel awards. The future laureates included Heisenberg, Pauli, Born, Dirac, de Broglie and Schrödinger, joining Einstein, Planck and Bohr in winning this most prestigious physics award for their contributions to the creation of quantum physics. Pascual Jordan, who worked with Heisenberg and Born, was not invited to the conference, perhaps because his pronounced stutter made public speaking a trial for both him and his audience. Jordan was also passed over for a

Nobel Prize, despite numerous nominations, but that may have had much more to do with his ardent pro-Aryan leanings.

Immediately after the Brussels conference, personal tragedies, politics and war overtook the fragile new physics while it was still tottering on shaky legs. The men who had created quantum physics scattered, and there was no going back to ponder the problems that had been left unresolved before the rush of experimental success in the 1930s made looking back seem quite unnecessary.

By their very nature, revolutions are fraught with uncertainty about the future, but the breaking apart of old structures and belief systems seems necessary in order to allow the light of new ideas to penetrate. There was no obvious point at which the old order in physics was overthrown by the new quantum variety—no queen beheaded, university razed or tyrant whisked off to a country without extradition treaties—but neither was there a specific point at which Newtonian physics replaced Aristotelian physics. Yet if one were pressed to identify a crucial turning point in the quantum revolution, the 1927 Solvay Conference would be a good choice. The conference loomed as a deadline for the physicists who would present to the august ensemble three competing versions, even if they were hastily-hammered-together and incomplete presentations; it was also the catalyst that finally brought them together in the same place.

Like the showdown between Wyatt Earp and the Clanton gang at the OK Corral, the conference was a fight to see which side would emerge the winner. Unlike the shootout at the famed corral, however, when the shouting was over in Brussels, there was no nice, tidy conclusion with clearly defined winners and losers. The story of the "quantum ten" and the confusion and uncertainty that have bedevilled the development of quantum physics undermine the idea that quantum physics was all figured out a long time ago.

After the upheaval of the Second World War, the story of the development of quantum physics was rewritten and a scientific mythology emerged. According to this postwar revision, the version of quantum physics promoted by those working with Niels Bohr in Copenhagen had won the day at the 1927 Solvay Conference and been declared the winner. And, this story insisted, all the problems with quantum physics had been settled at that time. There was, therefore, no need to revisit the creation of quantum physics because all the issues and questions had already been dealt with.

This hardly makes sense when leading physicists have been saying for years that nobody understands quantum physics. Nobel laureate Murray Gell-Mann is often quoted as saying, "We all know how to use and how to apply it to problems; and so we have learned to live with the fact that nobody can understand it."[8] Richard Feynman said much the same in 1965 in a BBC interview, and so did Steven Weinberg when he admitted in 1992 that he was a little uncomfortable knowing he'd spent his life working within a field that nobody understands.[9] How could all the questions about quantum physics have been answered if it's still not understood by its practitioners?

There continues to be a lot of resistance in the physics community to talking about such questions, since it does rather undermine the authority of the professionals to whom people look for an explanation of their world if the professionals don't understand it themselves. In its own way, this fundamental incomprehensibility of quantum physics has become the proverbial elephant in the living room.

Physicists and their students are still hearing the argument that quantum physics was fully worked out and satisfactorily explained eight decades ago, and popular science books reinforce that idea by routinely replaying the postwar mythology of the development of quantum physics. Indeed, as science writer George Johnson recently noted, "The story of the quantum revolution has been told so many times that it has become as ritualized as the stations of the cross."[10]* But another look at the turbulent development of the new science, including its very fallible creators, tells a much different tale of what really happened—a story of passion, tragedy, ambition and science. Perhaps a re-examination of how quantum physics was created can shed some small light on why, after eighty years, physicists are still having so much trouble reconciling the classical and quantum worlds. And preferably, this reappraisal will take place before modern science starts heading down the path taken by the Eleatics.

*The stations of the cross, part of a ritual of the Roman Catholic church, are depictions of fourteen events in the journey of Jesus from the time he was condemned to death until he was laid in his tomb. The faithful visit each station in turn, meditating and praying.

Chapter Two

THE QUANTUM SHOWDOWN

Our life is divided betwixt folly and prudence: whoever will write of it only what is reverent and canonical will leave one-half behind.

MICHEL DE MONTAIGNE

The art deco salon, with its stylish mosaics, opulent wood panelling and stained glass windows, was a suitably grand backdrop for what was shaping up to be a dramatic and pivotal moment in the development of modern science. The Fifth Solvay Conference at the Institut de Physiologie in Parc Léopold, Brussels, began October 24, 1927, and there was a powerful sense amongst the assembled scientists that they were witnessing a major turning point in the world of science.

Right from the beginning, there was a palpable excitement in the air. Almost all the key players in the development of quantum physics were there. The theme of the conference was "Electrons and Photons," but everyone knew it was really about quantum physics. Over the previous couple of years, an incredible amount of innovative thinking and sheer hard work had gone into formulating the new science, but there was no consensus about how the new physics worked or what it meant. And now the handful of scientists who had hammered it all together were about to present to their peers three competing versions—three factions hoping to persuade the august assembly that their theory was the right one.

Paul Ehrenfest had a niggling feeling that he was at the conference under false pretenses. He was, in his own estimation, an underachieving scientist from a small university in the Dutch city of Leiden. He wasn't sure he belonged in this rarefied company of Nobel laureates and the mathematically gifted young scientists who had done so much to make quantum physics a real science. He'd once revealed to his dear friend Albert Einstein, "I hop around among all of you big beasts like a harmless and helpless frog who is afraid of being squashed."[1] He still felt that way.

This wasn't Ehrenfest's first Solvay appearance. He'd been at the third conference, in 1921, but that time he'd presented a paper on behalf of Niels Bohr, another of his dear friends. The focus of the 1921 conference had been "Atoms and Electrons," and it would hardly have been a thorough discussion without a contribution from Bohr about his remarkable, if baffling, model of the quantized atom. But Bohr had been under a lot of stress at the time, overseeing the opening of his new Institute of Theoretical Physics in Copenhagen, and together with the demands of his expanding family, he'd worked himself into a state of exhaustion. Ehrenfest stepped in and offered to read Bohr's not-quite-finished paper, along with work of his own, and save him the trip from Copenhagen to Brussels.

Ehrenfest knew just about everybody at the conference, some very well. A quick glance around the room revealed half a dozen Nobel laureates, Bohr and Einstein among them. The white-bearded Hendrik Lorentz, whom Ehrenfest considered a father figure, had a Nobel Prize, as did the recently retired doyen of German physics, Max Planck. Marie Curie was still the lone woman at Solvay. She had a Nobel Prize for physics, likewise British experimentalist Lawrence Bragg. American experimentalist Arthur Compton had just got the nod for the 1927 prize. If Ehrenfest felt just a little inferior, he figured he had good reason.

But Ehrenfest was intimidated by more than just the award winners. In terms of career advancement, it was a significant honour to be invited to a Solvay conference, and it was an even bigger honour for a small group of young men with the ink barely dry on their doctoral degrees. They formed a kind of "boys' club." Paul Dirac was the youngest at twenty-five, Werner Heisenberg was almost twenty-six and Wolfgang Pauli, twenty-seven. Pascual Jordan hadn't been invited, even though it could be argued that his mathematical contributions were on par with those of Dirac. Jordan had a terrible stutter that ruled out public speaking, but, given that he had yet to complete the habilitation that was required after receiving a doctoral degree, he was unlikely to have rated an invitation to such an elite gathering anyway. Jordan was born a few months after Dirac, so if he had been invited, he would have been the youngest scientist in the room. At times like this, Ehrenfest could feel every one of his forty-seven years.

With one exception, the boys' club was collected, as usual, around Bohr. Heisenberg, Pauli and Dirac had all spent time with Bohr in Copenhagen, where Heisenberg had also been his assistant. All three had also been at Göttingen University over the past two years, working with Max Born, another of Ehrenfest's friends. Pauli and Heisenberg had both served as Born's assistants, although Pauli had lasted only a few months in the quiet backwater of Göttingen before heading to the big city lights (and nightclubs) of Hamburg. Jordan was Born's current assistant. To the physics community, Bohr, Heisenberg, Pauli, Dirac, Born and Jordan were the key players in the formidable Copenhagen–Göttingen school of quantum physics.

Born and Ehrenfest had been friends for a long time, so Ehrenfest knew what was going on at Göttingen. And because Ehrenfest and Bohr were also close friends, he knew what was happening at Copenhagen. For most of the preceding two years, the collaboration on the quantum atom that had been going on between Copenhagen and Göttingen seemed to have worked rather well. Heisenberg, Pauli and Dirac travelled back and forth between the two institutions, all of them spending time with both Bohr in

Copenhagen and Born at Göttingen. Only those who were privy to what was really going on in the two research centres knew about the friction and personal animosities playing out behind the scenes.

To the rest of the physics community, the Copenhagen and Göttingen collaborators presented a facade of unity and harmony. They knew it made their version of the new physics stronger if it looked as if they were all singing from the same songbook. But by the time of the conference, no one knew better than Born how much the Göttingen efforts were being sidelined. The new physics was being presented under the Copenhagen banner, as if the Göttingen contribution had been trivial or inconsequential. It wasn't Copenhagen and Göttingen anymore; it was just Copenhagen. It was obvious to Born that Heisenberg was shouldering both him and Jordan out of the picture, but it didn't seem that Born could summon the energy any longer to fight for Göttingen's fair share of the credit.

Heisenberg wasn't orbiting around Bohr like some of the other young men. He'd been a Bohr protégé, but that was over now. Heisenberg was the quintessential handsome German lad, fair-haired and blue-eyed. Despite his youth, he had buckets of self-confidence, as well as a cheeky grin that could disarm his colleagues even as he was "borrowing" their ideas. While Pauli and Jordan didn't seem to mind, Born did.

Ehrenfest knew that Bohr and Heisenberg had been at loggerheads during the past year, clashing over how to create a coherent theory of the new quantum physics. It had been a painful time for Bohr, and the two men could no longer work together. But word was out that the ambitious Heisenberg had scored the kind of coup he'd been shooting for. His self-serving competitiveness had just paid off. Shortly before the conference, Heisenberg was notified that he'd been selected as a professor of theoretical physics at the University of Leipzig, and at a lucrative salary. He was about to become Germany's youngest full professor, with every intention of establishing Leipzig as the world centre for the study of the new quantum physics.

Pauli, swaying back and forth as he often did, looked glum. Was he hung over? The portly Pauli was very fond of the nightclub scene and had something of a reputation for his copious alcohol consumption. It wasn't something Ehrenfest had witnessed first-hand, even when Pauli visited him in Leiden. Ehrenfest himself was an abstainer. Smoky, noisy bars were not his cup of tea, and his wife did not allow alcohol in the house. The Hamburg nightclubs were known to be Pauli's refuge when he was having emotional difficulties, and even when he was not. Pauli had once told a friend, "I've found drinking wine to be very agreeable. After the second bottle of wine or champagne, I usually become good company (which I never am when sober) and can, under these circumstances, make a very good impression on my surroundings, especially if they are feminine!"[2]

Pauli demanded a great deal of himself, pushing himself to make significant breakthroughs in physics and sinking into depression whenever he hit a dry spell. Pauli also had a reputation for being brutally critical of his Hamburg students and physics colleagues should he spot a shaky argument or weak assumption in their work, which earned him the nicknames "whip of God" and "frightful Pauli."[3] As long as one wasn't the target of his sharp tongue, Pauli's appreciation for a clever prank and his endearing clumsiness made him easy to like. Ehrenfest sometimes teasingly addressed Pauli in his letters as "Sanct Pauli," a reference to the red-light district and nightclub scene that Pauli frequented.[4]

Ehrenfest knew that Pauli and Heisenberg had been students together at the University of Munich, and that Pauli was one of the few people whose criticism the rather arrogant Heisenberg would listen to. When Heisenberg started galloping off in some new direction with a poorly worked out theory, it was usually Pauli who reined him in. But things had grown a little tense between the two over the past few months. When Heisenberg turned to Pauli for help when he and Bohr were fighting over the final details of the theory for quantum physics, Pauli had been unusually distant and unsupportive. In the stressful weeks before the Solvay conference, Bohr ended up looking to Pauli for help, not Heisenberg.

Ehrenfest didn't know a lot about Dirac, the youngest of the boys' club at the conference. Dirac was tall and thin and already a little stooped. Dressed in a sombre black suit, he looked for all the world like an anxious undertaker. The taciturn young Englishman seemed to have appeared out of nowhere two years previously, armed with his own take on the mathematics of quantum mechanics. He was definitely not the chatty sort; someone had jokingly suggested that his vocabulary consisted solely of "yes," "no" and "I don't know." Dirac preferred to let his mathematics do the talking for him. He had been to Leiden for a few days that summer, but even Ehrenfest, with his keen interest in people, had been unable to get the introverted Dirac to open up.

Ehrenfest watched Max Born chatting quietly with Marie Curie and Paul Langevin, and what he saw worried him. He wasn't concerned that Born's attentions to the only woman in the room were inappropriate—far from it. Born was very attached to his wife, and Curie's days as a femme fatale were long past. She was now a sad-faced and grey woman approaching her sixtieth birthday, her eyes clouded with cataracts. It was not easy to imagine this severe and unsmiling woman being at the heart of a romantic scandal. It had started in 1911 when Curie and Langevin, colleagues from Paris, both attended the First Solvay Conference. They arrived home from Brussels to face public outrage because Langevin's vengeful wife had gone to the papers with the story that her husband had eloped with Curie.

The romance between the widow Curie and the married Langevin caused such a public outcry that the Swedish Academy, about to announce Curie's second Nobel award, was having second thoughts. The Academy went ahead with the award but suggested to Curie that she not attend the ceremony, a piece of advice she ignored. The scandal spawned at least five duels in defence of Curie's honour. Fortunately, the duels resulted in only minor wounds, and the challenge Langevin took up resulted in no bloodshed at all and left his trademark handlebar moustache intact.[5] Sixteen years later, the grand passions of that affair had long since cooled.

Einstein was at the 1911 Solvay Conference, and had been amused by the idea of Curie being at the centre of a romantic scandal. "She has a sparkling intelligence," he said of her, "but in spite of her passionateness she is not attractive enough to become dangerous to anyone."[6] Ehrenfest knew all too well that Einstein's taste in female companions ran to something rather more flamboyant than Madame Curie—or Einstein's own wife, for that matter.

Born, on the other hand, was very much in love with his wife, Hedi. Ehrenfest and Born had been friends for a long time, and Ehrenfest knew that his friend tended to fuss over his health, often retreating to a spa or resort to recover, and right now he didn't look at all well. Part of his problem was the travelling. In the last few weeks Born had been to Italy for a conference and then headed to Bristol, England, to receive an honorary degree before rushing to Brussels. He was spending a great deal of time away from home and Hedi. Born loved her desperately, but there was a chill in their relationship that was hard to miss, and he was afraid he was losing her.

Born's worry was justified. Hedi had confided to Ehrenfest that she had befriended a mathematician who lived just down the street from the Born household, a man who just happened to be one of Ehrenfest's long-time friends from their Vienna school days. The conference was hardly the time or place to break the news to Born. He already looked like a man on the edge of a nervous breakdown.

Rather, Ehrenfest would have liked to ask Born if he was concerned about his current assistant at Göttingen, Pascual Jordan. There was no question that Jordan was a brilliant young mathematician, but he was also an ardent right-wing nationalist. Jordan was certainly not spouting nasty anti-Semitic propaganda like some physicists at German universities, but maybe that was only because

Jordan's speech impediment made it difficult for him to complete a sentence. Even though Born had converted to Lutheranism to please his wife, he was still a Jew. So were Ehrenfest and Einstein, and even Bohr was half Jewish. Jordan, as far as Ehrenfest knew, had always treated Born with respect, but Göttingen, like other German universities, was proving to be an attractive recruiting ground for the fervour and fanaticism of the National Socialist Party headed by Adolf Hitler.

Ehrenfest wondered if Born tolerated Jordan's politics out of plain old-fashioned guilt. Jordan had written a paper on a new aspect of quantum physics nearly two years earlier and had given it to Born for publication in a physics journal. Unfortunately, Born had packed it away as he headed off on yet another trip, and he didn't find it until six months later. By then, both Dirac and an Italian scientist had come up with the same idea and sent their work off for publication, while Jordan's paper lay at the bottom of one of Born's suitcases. Born still felt sick about the damage he feared he'd done to the young man's career.

Ehrenfest also knew that Born was still hurt by the souring of his long friendship with Einstein. They were both scientists; they should have been able to get past their ideological differences about quantum physics. In Born's opinion, Einstein had turned his back on the struggling Copenhagen and Göttingen physicists right when they were lost in a quantum wilderness and just when the "true believers," as they considered themselves, needed their leader and standard bearer.

Even without Einstein's help, the Copenhagen and Göttingen schools had, it appeared, finalized their version of quantum mechanics, but there was competition. Erwin Schrödinger and Prince Louis de Broglie both had their own versions to sell, but neither belonged to a "school" of physics. They, like Einstein, worked alone.

Ehrenfest recalled his first meeting with Schrödinger, back in 1912 at the Boltzmann library in the University of Vienna, his old alma mater. He'd dragged the young man, who had only recently graduated, off to lunch and then to a coffee house where he knew they could write equations in pencil on the white marble tabletops while enthusiastically discussing the latest developments in physics.[7]

Schrödinger was the most obviously unconventional person in the conference room. Perhaps it was something he deliberately cultivated. He had arrived in Brussels dressed in lederhosen, with a rucksack on his back, as if he'd just come down from an Alpine hike.[8] Right after the conference Schrödinger would be off to the University of Berlin to begin his duties as Planck's successor as chair of theoretical physics. Ehrenfest wondered if Berlin society was ready for the Viennese scientist.

Schrödinger was quite unabashed about his enjoyment of the pleasures of the flesh, particularly if the flesh belonged to nubile young women. Beak-nosed and bespectacled, he wasn't exactly the image of a Casanova, but he and his wife, Anny, had been part of a rather liberal crowd in Zurich. It was not only acceptable for husbands and wives in their circle to have extramarital affairs, it was expected.[9] Ehrenfest had heard that Schrödinger's big breakthrough in quantum mechanics two years earlier had come during a holiday tryst in the Alps with one of his many lovers. Ehrenfest couldn't quite fathom the Schrödinger marriage. He adored his own wife, Tatyana, even if they were going through a bit of a bad patch at the moment, and he simply could not imagine himself getting involved with another woman. Still, Berlin nightlife had become a carnival of frenzied licentiousness and excessive passions. Maybe the Schrödingers would fit right in.

But right now, Schrödinger had a fight on his hands. He was about to square off against the Copenhagen and Göttingen physicists in an attempt to convince the assembled scientists that his version of quantum physics was much better than theirs. The theoretical physics that Schrödinger had come up with on his erotic Christmas holiday had stunned the Copenhagen and Göttingen crews, especially since they had assumed they were the only game in town. How had an outsider, working alone, come up with a different explanation for the quantized atom that looked so much better than theirs? It wasn't long before the Copenhagen and Göttingen scientists were integrating Schrödinger's mathematics and physics into their own version, even as they publicly ridiculed his work. Things had got a little out of hand for a while when Heisenberg and Jordan went overboard with their attack on Schrödinger. But that was only because Schrödinger's version of the quantum atom was immediately seen as a serious challenge to Copenhagen's primacy.

Since Schrödinger's mathematics was now integrated into the Copenhagen model, which was far and away the preferred method being used by physicists, he'd already won half the battle. But could Schrödinger persuade the audience that his interpretation of quantum physics should also prevail? The Copenhagen group had come up with their interpretation only in the last couple of weeks, making sure it was obviously and clearly different from what Schrödinger was going to pitch. But it was a confusing theory. Fortunately, the Copenhagen group had the credibility of the greatly respected Niels Bohr on their side, as well as the powerhouse of the two leading theoretical physics institutes, Copenhagen and Göttingen. On his side, Schrödinger had . . . well, just Schrödinger. And maybe Einstein and Planck.

Although most of the people in the room were invited scientists, some were younger men who had been chosen to act as scientific secretaries, taking notes on the proceedings and writing them up for publication after the conference. Even if they were not formal participants, the scientific secretaries had the rare opportunity to rub shoulders with some of the top physicists in the world, and the privilege of a ringside seat at a most important meeting. Maurice de Broglie had been one such fortunate beginner. He'd completed his doctoral degree in 1908 under the supervision of Paul Langevin in Paris, after defying his family's wishes and trading a naval career for physics. He'd barely begun his studies when his father died and Maurice inherited the title of sixth duc de Broglie, and not long afterwards, he'd been invited to accompany Langevin and Curie to the First Solvay Conference in 1911 as a secretary.

Ehrenfest remembered meeting Maurice at the Solvay conference of 1921, where Maurice was a presenter as well as a scientific secretary. His family's wealth and prominent social status in France did not exempt him from having to make his mark in the physics community the same as every other scientist. Maurice had built his own laboratory in his large house in Paris, and he had made a name for himself as an excellent experimentalist. Apparently, Maurice had brought his younger brother Louis with him to the First Solvay Conference back in 1911, and that had inspired Louis to become a physicist himself. Now, Prince Louis de Broglie was about to present his own theory of quantum physics to the assembled scientists. It was too bad, thought Ehrenfest, that Maurice couldn't be present to see it.

Ehrenfest didn't know the young prince. The de Broglie family occupied a social stratum that was very different from anything Ehrenfest had ever experienced. They had a long history in politics and diplomacy in the upper echelons of French society, and at least one de Broglie had lost his head to Madame Guillotine in the French Revolution. Ehrenfest, on the other hand, was the son of a Viennese grocer, so Parisian royal affairs were foreign to the world he knew.

But Ehrenfest did know that Einstein had initially supported Louis de Broglie's version of quantum physics and then backed off a bit. That signalled to Ehrenfest that de Broglie was likely to have a tough time bringing the assembled scientists onside. Certainly, the young prince had done little to endear himself to the Copenhagen scientists. If anything, he seemed to have gone out of his way to irritate them by challenging the science they were doing. It didn't help de Broglie's case that his own ideas were often wrong, or that, with his crooked teeth, *petite moustache* and mop of curly hair, he looked more like the popular cinema comedian Charlie Chaplin than a serious scientist. He would be a sitting duck for Heisenberg's ridicule and Pauli's acid tongue.

At any rate, the assembled scientists and secretaries quickly found their chairs as Lorentz took his place at the front of the salon. Lorentz had chaired all four of the previous Solvay conferences as well. The retired Dutch scientist was a measured and diplomatic man with more than the necessary fluency in German, French and English. But most important, he possessed the ability to keep the sometimes opinionated and headstrong scientists in order. The beautiful salons of the Institut de Physiologie were hardly suited to the rowdy, unconstrained behaviour of a beer hall. Not that Ehrenfest would have minded that, sans the beer, of course. He quite enjoyed an enthusiastic debate, but his colleagues often seemed more at home in a formal atmosphere that he felt worked against an open exchange of ideas. Still, there was a buzz of excitement in the room that all the starched collars and tightly buttoned waistcoats could not suppress.

Adding to the undercurrents was an awareness that this was the first time German scientists had been allowed into Belgium since the end of the Great War. The last time Germans had entered Belgium, things had not gone at all well. German scientists had been banned from attending all international science conferences after the surrender in 1918. Einstein was an exception, partly because he had long ago obtained Swiss citizenship, partly because he had become an international celebrity. But since German scientists had done so much of the work on quantum physics, it would have been pointless to hold a conference on the new science without them.

Lorentz, who also organized the conference, had sought a personal audience with Albert I, King of the Belgians, to plead on behalf of the German physics community. According to Lorentz, he and the king had seen eye to eye on the issue of anti-German sentiment:

> His Majesty expressed the opinion that seven years after the war, the feelings which they aroused should be gradually damped down, that a better understanding between peoples

> was absolutely necessary for the future, and that science could help to bring this about. He also felt it necessary to stress that in view of all that the Germans had done for physics, it would be very difficult to pass them over.[10]

Still, the echoes of the war were an unwelcome reminder of the troubling world beyond the scientific presentations, which all the professional camaraderie couldn't hide. Everyone at the conference knew about the vitriolic attacks Einstein was subjected to in Germany. There were rumours of assassination attempts, or at least death threats. For some Germans, the surrender of 1918 had been both humiliating and enraging. How could they have been defeated when not a single battle had taken place on German soil? So they looked for scapegoats to blame for Germany's defeat, and the Jews were a convenient target.

The success of Einstein's theory of general relativity, experimentally verified just as the war ended, had made him an international star. It had also provided the right-wing factions in German politics with a highly visible target. With armed militias roaming the streets of Berlin, inciting violence and chaos in order to undermine the shaky republican Weimar government, it seemed almost inevitable that highly placed Jews would be targets for German wrath. In the summer of 1922 the foreign minister, Walther Rathenau, Germany's highest-placed Jew and one of Einstein's friends, was assassinated in the street. More and more political figures, Jewish or otherwise, were falling victim to right-wing nationalist paramilitary forces, and the German government seemed unable to put a stop to the violence. Max Planck, one of Germany's leading physicists, who had helped bring Einstein to Berlin in the first place, had pleaded with him not to abandon Germany. But in a quiet talk with Planck, Einstein acknowledged the jeopardy he faced. "A number of people who deserve to be taken seriously," Einstein had told him, "have independently warned me not to stay in Berlin for the time being, and, most especially, to avoid all public appearances in Germany. I am said to be among those whom the nationalists have marked for assassination."[11]

Ehrenfest and his wife did their best to persuade Einstein to come and stay with them in Leiden in 1922, but just as during the Great War, Einstein had declined to leave Germany unless the situation became dire. Fortunately, he had already committed himself to lecturing overseas in the fall of 1922, and thus had a good reason to leave Berlin. He boarded a ship sailing for Japan in October, thereby missing the announcement that he'd won a Nobel Prize for physics. He missed the ceremony in December as well.

Despite the political instability and unrest in Germany, the big question buzzing around the conference was, "What will Einstein say?" Indeed, "all over Europe"[12] people were waiting to hear Einstein's verdict on the new physics. Because of his celebrity status around the world, just about anything Einstein said made big news. But he had yet to make a public statement about quantum physics, so no one could know for sure what he was going to say, not even the physicists gathered in the salon.

Nobody was more aware than Ehrenfest of the deep divisions between Einstein and Bohr over the direction the new physics was taking. But what Einstein would say at the conference, to be recorded as part of the published proceedings, was not necessarily what he would say in the privacy of Ehrenfest's living room. Ehrenfest had hoped Bohr and Einstein could find some common ground, maybe compromise a little. He'd already tried to mediate by arranging some rare uninterrupted time for his friends to sit down and talk to each other, but his best efforts had failed.

Bohr wasn't giving a presentation at the conference, but the interpretation of quantum physics he'd presented a month earlier at a conference in Italy was undoubtedly going to come up for discussion. Ehrenfest hadn't been there, but some of the others at the conference had. Ehrenfest just hoped he could follow what Bohr was trying to say; he'd learned long ago that understanding Bohr wasn't easy. When Ehrenfest had visited the Copenhagen Institute for the first time in 1921, Bohr's younger brother Harald, a professor of mathematics in Copenhagen, had reassured Ehrenfest that he wasn't alone. "When Niels tells me something," Harald confided to Ehrenfest, "I absolutely don't understand what he is talking about and what he is driving at for fifty-nine minutes; but in the sixtieth minute a light suddenly dawns and I see that everything he said previously was absolutely necessary."[13]

Einstein had not been at the conference in Italy either, so no one really knew what his reaction would be to Bohr's new theory. Bohr had sent Einstein a copy of his talk, but this would be the first time the two men would have an opportunity to discuss it. Ehrenfest had a sinking feeling that his two dearest friends were heading for a showdown, a clash of the titans of science—and only one would come out a winner.