

# FROM CERTAINTY TO UNCERTAINTY

The Story of Science and Ideas  
in the Twentieth Century

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# CONTENTS



Preface	ix
1 Quantum Uncertainty	1
2 On Incompleteness	27
3 From Object to Process	52
4 Language	71
5 The End of Representation	90
6 From Clockwork to Chaos	115
7 Re-envisioning the Planet	154
8 Pausing the Cosmos	187
Postscript	215
Appendix: Gödel's Theorem	217
Index	223



## PREFACE



Que sais-je? (What do I know?) *Montaigne*

**T**he first year of a new century always appears auspicious. The year 1900 was no exception. Americans welcomed it in with the three Ps: Peace, Prosperity, and Progress. It was the culmination of many outstanding achievements and looked forward, with great confidence, to a century of continued progress. The twentieth century would be an age of knowledge and certainty. Ironically it ended in uncertainty, ambiguity, and doubt. This book is the story of that change and of a major transformation in human thinking. It also argues that, while our new millennium may no longer offer certainty, it does hold a new potential for growth, change, discovery, and creativity in all walks of life.

On April 27, 1900, Lord Kelvin, the eminent physicist and president of Britain's Royal Society, addressed the Royal Institution, pointing out "the beauty and clearness of the dynamical theory." Finally Newton's physics had been extended to embrace all of physics, including both heat and light. In essence, everything that could be known was, in principle at least, already known. The president could look ahead to a new century with total conviction. Newton's theory of

motion had been confirmed by generations of scientists, and it explained everything from the orbits of the planets to the tides, the fall of an apple, and the path of a projectile. What's more, during the preceding decades James Clerk Maxwell had established a definitive theory of light. Taken together, Newton's and Maxwell's two theories appeared to be capable of explaining every phenomenon in the entire physical universe.

Yet the cusp of the twentieth century presents us with an irony. 1900 was a year of great stability and confidence. It saw the consolidation and summing up of many triumphs in science, technology, engineering, economics, and diplomacy. As Senator Chauncey Depew of New York put it, "There is not a man here who does not feel 400 percent bigger in 1900 than he did in 1896, bigger intellectually, bigger hopefully, bigger patriotically," while the Reverend Newell Dwight Hillis claimed, "Laws are becoming more just, rules more humane; music is becoming sweeter and books wiser." Yet, at that very moment other thinkers, inventors, scientists, artists, and dreamers, including Max Planck, Henri Poincaré, Thomas Edison, Guglielmo Marconi, Nikola Tesla, the Wright brothers, Bertrand Russell, Paul Cézanne, Pablo Picasso, Marcel Proust, Sigmund Freud, Henry Ford, and Herman Hollerith were conceiving of ideas and inventions that were to transform the entire globe.

1900 was the year in which flash photography was invented and speech was first transmitted by radio. Arthur Evans discovered evidence of a Minoan culture and the United States backed its paper currency with gold. Once the Gold Standard had been adopted, was there anything that could stand in the way of a greater degree of confidence in the future of their world?

1900 also represents the culmination of a period of rapid discovery. In the two previous years the Curies had discovered radium and J. J. Thomson the electron. Von Linde had liquefied air and Aspirin had been invented. Edison's Vitascope together with the magnetic recording of sound heralded the age of the movies.

Thanks to Nikola Tesla's inventions in alternating current, the city of Buffalo was receiving electrical power generated by Niagara Falls. Count von Zeppelin constructed an airship, the Paris Metro opened,

and London saw its first motorbus. By 1902, the transmission of data by telephone and telegraph was already well established, and the first faxed photographs were being transmitted.

1900 also saw a link between Britain's Trades Union Congress and the Independent Labour Party, a move that would eventually lead to the establishment of the welfare state. With such a dream of social improvement people seemed justified in believing that the future would provide better housing, education, and health services. Homelessness would be a thing of the past and, while those thrown out of work would need to tighten their belts a little, they would be supported by the welfare state and would no longer face suffering and hardship.

Europe also experienced a great sense of stability in 1900. Queen Victoria, who had ruled since 1837, was still on the throne. She had become known as "the Grandmother of Europe," since her grandchildren were now part of the European monarchy. Indeed all of the European kings and queens, as well as the Russian royal family, were a part of a single international family presided over by Victoria. It was for this reason, diplomats believed, there would never be a war within Europe.

On May 18, 1899, at the prompting of Czar Nicholas II's minister of foreign affairs, 26 nations met at The Hague for the world's first peace conference. There they established an International Court to arbitrate in disputes between nations. The conference outlawed poison gases, dum dum bullets, and the discharge of bombs from balloons. Wars and international conflicts would be things of the past. The world itself was moving toward a new golden age in which science and technology would be put to the service of humanity and world peace

Yet when people look to a golden future they should not forget the role of hubris. Often our predictions return to haunt us. It is particularly ironic that in this same year, 1900, ideas and approaches began to surface that were to transform our world, our society, and ourselves in radical and unpredictable ways.

What were those tiny seeds that were destined to blossom in such unexpected directions? In 1900 Max Planck published his first paper on the quantum, and young Albert Einstein graduated from the Zurich Polytechnic Academy. A year later Werner Heisenberg was born. These three physicists would create the great revolutions of modern science.

In 1900 Henri Poincaré was working on an abstruse technical difficulty involving Newtonian mechanics. Over half a century later this would explode into chaos theory. Astronomers were looking forward to the opening of the great telescopes at Mount Wilson in 1904 and, in the decades that followed, Edwin Hubble would use these instruments to discover that the universe was far vaster than ever believed and, moreover, that it was continually expanding.

In 1900 biologists rediscovered the work of an obscure mid nineteenth century monk, Gregor Mendel. Ignored by the scientific community in his own day, Mendel had examined the way physical characteristics are inherited when different varieties of garden peas are crossed. Who would have guessed that exactly a century after this rediscovery of the basis of genetic inheritance, the completion of the Human Genome Project would be announced?

This same year, 1900, saw the publication of Sigmund Freud's *Interpretation of Dreams*. Much more rational than a Victorian dream book, which typically flirted with divination and the occult, it demonstrated that dreams are "the royal road to the unconscious" and, in turn, that our waking lives are ruled by the irrationality of the unconscious. That unconscious had a potential for violence and human irrationality that was to be powerfully demonstrated again and again during the twentieth century.

At the end of the nineteenth century Percival Lowell used his fortune to establish his own observatory at Flagstaff, Arizona, with the aim of discovering life on Mars. In 1900 H. G. Wells, inspired by these ideas, published *War of the Worlds*, with its image of the mass destruction of the human race. Ironically the real possibility of global destruction in the twentieth century did not arise from little green men from Mars but from human-made weapons of mass destruction.

1900 was the year when the young philosopher Bertrand Russell heard Giuseppe Peano speak at a conference in Paris. The lecture so inspired Russell that he devoted his life's work to the discovery of certainty in mathematics and philosophy. How this mathematical Holy Grail itself was eventually subverted forms the core of Chapter 2.

In 1900, inspired by the writings of John Ruskin, Marcel Proust visited Venice. He abandoned the novel on which he had been working

and, determined to seek some new way of expressing “man’s” confrontation with eternity, he embarked on a master plan that was to terminate in one of the major literary works of the twentieth century. It was also the year that the 18-year-old James Joyce, after having his first article published, decided to become a full-time writer. In this same year Picasso had his first exhibition and made a trip to Paris, an event that was to have a profound effect on art in the twentieth century. 1900 was also the year in which Paul Cézanne was working on his famous studies of Montagne Sainte-Victoire. The works he produced there had a revolutionary effect on painting and produced yet another form of doubt as he questioned the certainty of what he was seeing.

In the previous year Henry Ford had formed the Detroit Motor Company, which would produce the famous Model T, a car that transformed American society. Add to this Ford’s discovery of mass production through the assembly line and one understands in part why, when young Henry left his father’s farm, only a quarter of Americans lived in a city, yet, when he died, well over half of them were city dwellers. In 1900 there were 8,000 automobiles in the United States and 150 miles of paved road. Today the number of cars in the United States is close to 100 million.

A few years earlier, in 1896, Herman Hollerith had created the Tabulating Machine Company to speed up the processing of data using a system of punched cards. In 1911 the company’s name changed to International Business Machines. The radio vacuum tube had been invented (in 1904), and so both the physical components and the business infrastructure were already in place for the creation of the computer revolution.

In the same year as the creation of Hollerith’s Tabulating Machine Company, Henri Becquerel discovered the radioactivity of uranium. A few decades later, while studying Becquerel’s phenomenon, the German scientist Otto Hahn realized that the atom could be split. When knowledge of this process reached the United States, colleagues persuaded Einstein to write a letter to President Roosevelt recommending the building of an atomic bomb, out of the fear that Nazi scientists would do so first. And so was born the atomic age, and with it the possibility of the annihilation of all life on earth.

While the twentieth century began with confident certainty it ended in unsettling uncertainty. Never again will we have the same degree of pride in our knowledge. In our infatuation with science and technology we overestimated our ability to manipulate and control the world around us. We forgot the power of the mind's irrational impulses. We were too proud in our intellectual achievements, too confident in our abilities, too convinced that humans would stride across the world like gods.

Today we are wiser and more cautious. We are suspicious of great plans and global promises. We view with caution the sweeping proposals of experts and politicians. We savor unbounded optimism with a generous pinch of salt.

Above all we want a better world for ourselves, our children, and our children's children. We have learned that ordinary people can have a voice. We will not put our lives blindly into the hands of politicians and institutions. We demand to be heard and we know we can be effective.

Now let us return in more detail to the twentieth century and discover the various ways in which certainty dissolved into uncertainty. Each chapter that follows tells us something about uncertainty in the worlds of art, science, economics, society, and the environment. Each adds another layer to those increasingly complex questions: Who am I? What do I know? What does it mean to be human?

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## QUANTUM UNCERTAINTY



In 1900 Lord Kelvin spoke of the triumphs of physics and how Newton's theory of motion could be extended to embrace the phenomena of light and heat. His address went on to mention "two clouds" that obscured the "beauty and clearness" of the theory: the first involved the way light travels through space, the second was the problem of distributing energy equally among vibrating molecules. The solution Kelvin proposed, however, proved to be way off the mark. Ironically, what Kelvin had taken to be clouds on the horizon were in fact two bombshells about to create a massive explosion in twentieth century physics. Their names were relativity and quantum theory, and both theories had something to say about light.

Light, according to physicists like Kelvin, is a vibration, and like every other vibration it should be treated by Newton's laws of motion. But a vibration, physicists argued, has to be vibrating *in* something. And so physicists proposed that space is not empty but filled with a curious jelly called "the luminiferous ether." But this meant that the speed of light measured in laboratories on earth—the speed with

which vibrations appear to travel through the ether—should depend on how fast and in what direction the earth is moving through the ether. Because the earth revolves around the sun this direction is always varying, and so the speed of light measured from a given direction should vary according to the time of year. Scientists therefore expected to detect a variation in the speed of light measured at various times of the year, but very accurate experiments showed that this was not the case. No matter how the earth moves with respect to the background of distant stars, the speed of light remains the same.

This mystery of the speed of light and the existence, or nonexistence, of the ether was only solved with Einstein's special theory of relativity, which showed that the speed of light is a constant, independent of how fast you or the light source is traveling.

The other cloud on Kelvin's horizon, the way in which energy is shared by vibrating molecules, was related to yet another difficult problem—the radiation emitted from a hot body. In this case the solution demanded a revolution in thinking that was just as radical as relativity theory—the quantum theory.

## *Bohr and Einstein*

Special relativity was conceived by a single mind—that of Albert Einstein. Quantum theory, however, was the product of a group of physicists who largely worked together and acknowledged the Danish physicist Niels Bohr as their philosophical leader. As it turns out, the tensions between certainty and uncertainty that form the core of this book are nowhere better illustrated than in the positions on quantum theory taken by these two great icons of twentieth century physics, Einstein and Bohr. By following their intellectual paths we are able to discover the essence of this great rupture between certainty and uncertainty.

When the two men debated together during the early decades of the twentieth century they did so with such passion for truth that Einstein said that he felt love for Bohr. However, as the two men aged, the differences between their respective positions became insurmount-

able to the point where they had little to say to each other. The American physicist David Bohm related the story of Bohr's visit to Princeton after World War II. On that occasion the physicist Eugene Wigner arranged a reception for Bohr that would also be attended by Einstein. During the reception Einstein and his students stood at one end of the room and Bohr and his colleagues at the other.

How did this split come about? Why, with their shared passion for seeking truth, had the spirit of open communication broken down between the two men? The answer encapsulates much of the history of twentieth century physics and concerns the essential dislocation between certainty and uncertainty. The break between them involves one of the deepest principles of science and philosophy—the underlying nature of reality. To understand how this happened is to confront one of the great transformations in our understanding of the world, a leap far more revolutionary than anything Copernicus, Galileo, or Newton produced. To find out how this came about we must first take a tour through twentieth century physics.

## *Relativity*

Einstein's name is popularly associated with the idea that "everything is relative." This word "relative" has today become loaded with a vast number of different associations. Sociologists, for example, speak of "cultural relativism," suggesting that what we take for "reality" is to a large extent a social construct and that other societies construct their realities in other ways. Thus, they argue, "Western science" can never be a totally objective account of the world for it is embedded within all manner of cultural assumptions. Some suggest that science is just one of the many equally valid stories a society tells itself to give authority to its structure; religion being another.

In this usage of the words "relative" and "relativism" we have come far from what Einstein originally intended. Einstein's theory certainly tells us that the world appears different to observers moving at different speeds, or who are in different gravitational fields. For example, relative to one observer lengths will contract, clocks will run at differ-

ent speeds, and circular objects will appear ellipsoidal. Yet this does not mean that the world itself is purely subjective. Laws of nature underlie relative appearances, and these laws are the same for all observers no matter how fast they are moving or where they are placed in the universe. Einstein firmly believed in a totally objective reality to the world and, as we shall see, it is at this point that Einstein parts company with Bohr.

Perhaps a note of clarification should be added here since that word “relativity” covers two theories. In 1905, Einstein (in what was to become known as the special theory of relativity) dealt with the issue of how phenomena appear different to observers moving at different speeds. He also showed that there is no absolute frame of reference in the universe against which all speeds can be measured. All one can talk about is the speed of one observer when measured relative to another. Hence the term “relativity.”

Three years later the mathematician Herman Minkowski addressed the 80th assembly of German National Scientists and Physicians at Cologne. His talk opened with the famous words: “Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality.” In other words, Einstein’s special theory of relativity implied that space and time were to be unified into a new four-dimensional background called space-time.

Einstein now began to ponder how the force of gravity would enter into his scheme. The result, published in 1916, was his general theory of relativity (his earlier theory now being a special case that applies in the absence of gravitational fields). The general theory showed how matter and energy act on the structure of space-time and cause it to curve. In turn, when a body enters a region of curved space-time its speed begins to change. Place an apple in a region of space-time and it accelerates, just like an apple that falls from a tree on earth. Seen from the perspective of General Relativity the force of gravity acting on this apple is none other than the effect of a body moving through curved space-time. The curvature of this space-time is produced by the mass of the earth.

Now let us return to the issue of objectivity in a relative world.

Imagine a group of scientists here on earth, another group of scientists in a laboratory that is moving close to the speed of light, and a third group located close to a black hole. Each group observes and measures different phenomena and different appearances, yet the underlying laws they deduce about the universe will be identical in each of the three cases. For Einstein, these laws are totally independent of the state of the observer.

This is the deeper meaning of Einstein's great discovery. Behind all phenomena are laws of nature, and the form of these laws, their most elegant mathematical expression, is totally independent of any observer. Phenomena, on the other hand, are manifestations of these underlying laws but only under particular circumstances and contexts. Thus, while phenomena appear different for different observers, the theory of relativity allows scientists to translate, or transform, one phenomenon into another and thus to return to an objective account of the world. Hence, for Einstein the certainty of a single reality lies behind the multiplicity of appearance.

Relativity is a little like moving between different countries and changing money from dollars into pounds, francs, yen, or euros. Ignoring bank charges, the amount of money is exactly the same, only its physical appearance—the bank notes in green dollars or pounds, yen, euros, and so on changes. Similarly a statement made at the United Nations is simultaneously translated into many different languages. In each particular case the sound of the statement is quite different but the underlying meaning is the same. Observed phenomena could be equated to statements in different languages, but the underlying meaning that is the source of these various translations corresponds to the objective laws of nature.

This underlying reality is quite independent of any particular observer. Einstein felt that if the cosmos did not work in such a way it would simply not make any sense and he would give up doing physics. So, in spite of that word “relativity,” for Einstein there was a concrete certainty about the world, and this certainty lay in the mathematical laws of nature. It is on this most fundamental point that Bohr parted company with him.

## *Blackbody Radiation*

If Einstein stood for an objective and independent reality what was Niels Bohr's position? Bohr was an extremely subtle thinker and his writings on quantum theory are often misunderstood, even by professional physicists! To discover how his views on uncertainty and ambiguity evolved we must go back to 1900, to Kelvin's problem of how energy is distributed amongst molecules and an even more troubling, related issue, that of blackbody radiation.

A flower, a dress, or a painting is colored because it absorbs light at certain frequencies while reflecting back other frequencies. A pure black surface, however, absorbs all light that falls on it. It has no preference for one color over another or for one frequency over another. Likewise, when that black surface is warmer than its surroundings it radiates its energy away and, being black, does so at every possible frequency without preferring one frequency (or color) over another.

When physicists in the late nineteenth century used their theories to calculate how much energy is being radiated, the amount they arrived at, absurdly, was infinite. Clearly this was a mistake, but no one could discover the flaw in the underlying theory.

Earlier that century the Scottish physicist James Clerk Maxwell had pictured light in the form of waves. Physicists knew how to make calculations for waves in the ocean, sound waves in a concert hall, and the waves formed when you flick a rope that is held fixed at the other end. Waves can be of any length, with an infinite range of gradations. In the case of sound, for example, the shorter the wavelength—the distance between one crest and the next—the higher the pitch, or frequency, of the sound because the shorter the distance between wave crests, the more crests pass a particular point, such as your ear, in a given length of time. The same is true of light: long wavelengths lie toward the red end of the spectrum, whereas blue light is produced by higher frequencies and shorter wavelengths.

By analogy with sound and water waves, the waves of light radiated from a hot body were assumed to have every possible length and every possible frequency; in other words, light had an infinite number

of gradations from one wavelength to the next. In this way an infinity crept into the calculation and emerged as an infinite amount of energy being radiated.

## *The Quantum*

In 1900 Max Planck discovered the solution to this problem. He proposed that all possible frequencies and wavelengths are not permitted, because light energy is emitted only in discrete amounts called quanta. Rather than continuous radiation emerging from a hot body, there is a discontinuous, and finite, emission of a series of quanta.

With one stroke the problem of blackbody radiation was solved, and the door was opened to a whole new field that eventually became known as quantum theory. Ironically Einstein was the first scientist to apply Planck's ideas. He argued that if light energy comes in the form of little packages, or quanta, then when light falls on the surface of a metal it is like a hail of tiny bullets that knock electrons out of the metal. In fact this is exactly what is observed in the "photoelectric effect," the principle behind such technological marvels as the "magic eye." When you stand in the doorway of an elevator you interrupt a beam of light that is supposed to be hitting a photocell. This beam consists of light quanta, or photons, that knock electrons from their atoms and in this way create an electrical current that activates a relay to close the door. A person standing in the doorway interrupts this beam and so the door does not close.

The next important step in the development of quantum theory came in 1913 from the young Niels Bohr who suggested that not only light, but also the energy of atoms, is quantized. This explains why, when atoms emit or lose their energy in the form of radiation, the energy given out by a heated atom is not continuous but consists of a series of discrete frequencies that show up as discrete lines in that atom's spectrum. Along with contributions from Werner Heisenberg, Max Born, Erwin Schrödinger and several other physicists the quantum theory was set in place. And with it uncertainty entered the heart of physics.

## *Complementarity*

Just as relativity taught that clocks can run at different rates, lengths can contract, and twins on different journeys age at different rates, so too quantum theory brought with it a number of curious and bizarre new concepts. One is called wave-particle duality. In some situations an electron can only be understood if it is behaving like a wave delocalized over all space. In other situations an electron is detected as a particle confined within a tiny region of space. But how can something be everywhere and at the same time also be located at a unique point in space?

Niels Bohr elevated duality to a universal principle he termed “complementarity.” A single description “this is a wave” or “this is a particle,” he argued, is never enough to exhaust the richness of a quantum system. Quantum systems demand the overlapping of several complementary descriptions that when taken together appear paradoxical and even contradictory. Quantum theory was opening the door to a new type of logic about the world.

Bohr believed that complementarity was far more general than just a description of the nature of electrons. Complementarity, he felt, was basic to human consciousness and to the way the mind works. Until the twentieth century, science had dealt in the certainties of Aristotelian logic: “A thing is either A or not-A.” Now it was entering a world in which something can be “both A and not-A.” Rather than creating exhaustive descriptions of the world or drawing a single map that corresponds in all its features to the external world, science was having to produce a series of maps showing different features, maps that never quite overlap.

## *Chance and the Irrational in Nature*

If complementarity shook our naive belief in the uniqueness of scientific physical objects, certainty was to receive yet another shock in the form of the new role taken by chance. Think, for example, of Marie Curie’s discovery of radium. This element is radioactive, which means

that its nuclei are unstable and spontaneously break apart or “decay” into the element radon. Physicists knew that after 1,620 years only half of this original radium will be left—this is known as its half-life. After a further 1,620 years only a quarter will remain, and so on. But an individual atom’s moment of decay is pure chance—it could decay in a day, or still be around after 10,000 years.

The result bears similarity to life insurance. Insurers can compute the average life expectancy of 60-year-old men who do not smoke or drink, but they have no idea when any particular 60-year-old will die. Yet there is one very significant difference. Even if a 60-year-old does not know the hour of his death, it is certain that his death will be the result of a particular cause—a heart attack, a traffic accident, or a bolt of lightning. In the case of radioactive disintegration, however, there is no cause. There is no law of nature that determines when such an event will take place. Quantum chance is absolute.

To take another example, chance rules the game of roulette. The ball hits the spinning wheel and is buffeted this way and that until it finally comes to rest on a particular number. While we can’t predict the exact outcome, we do know that at every moment there is a specific cause, a mechanical impact, that knocks the ball forward. But because the system is too complex to take into account all the factors involved—the speed of the ball, the speed of the wheel, the precise angle at which the ball hits the wheel, and so on—the laws of chance dominate the game. As with life insurance, chance is another way of saying that the system is too complex for us to describe. In this case chance is a measure of our ignorance.

Things are quite different in the quantum world. Quantum chance is not a measure of ignorance but an inherent property. No amount of additional knowledge will ever allow science to predict the instant a particular atom decays because nothing is “causing” this decay, at least in the familiar sense of something being pushed, pulled, attracted, or repelled.

Chance in quantum theory is absolute and irreducible. Knowing more about the atom will never eliminate this element. Chance lies at the heart of the quantum universe. This was the first great stumbling

block, the first great division between Bohr and Einstein, for the latter refused to believe that “the Good Lord plays dice with the universe.”

## *Einstein: The Last Classical Physicist*

Even now, half a century after Einstein’s death, it is too soon to assess his position in science. In some ways his stature could be compared to that of Newton who, following on from Galileo, created a science that lasted for 200 years. He made such a grand theoretical synthesis that he was able to embrace the whole of the universe. Some historians of science also refer to Newton as the last magus, a man with one foot in the ideas of the middle ages and the other in rationalistic science. Newton was deeply steeped in alchemy and sought the one Catholick Matter. He had a deep faith in a single unifying principle of all that is.

Likewise Einstein, who was responsible for the scientific revolution of relativity as well as some of the first theoretical steps into quantum theory, is regarded by some as the last of the great classical physicists. As with Shakespeare, great minds such as Newton’s and Einstein’s appear to straddle an age, in part gazing forward into the future, in part looking back to an earlier tradition of thought.

When Einstein spoke of “the Good Lord” as not playing dice with the universe, he was referring not to a personal god but rather to “the God of Spinoza,” or, as with Newton, to an overarching principle of unity that embraces all of nature. The cosmos for Einstein was a divine creation and thus it had to make sense, it had to be rational and orderly. It had to be founded upon a deep and aesthetically beautiful principle. Its underlying structure had to be satisfyingly simple and uniform. Reality, for Einstein, lay beyond our petty human wishes and desires. Reality was consistent. It reflected itself at every level. Moreover, the Good Lord had given us the ability to contemplate and understand such a reality.

Einstein could have sat down at Newton’s dinner table and discussed the universe with him, something he was ultimately unable to do with Bohr. Bohr and quantum theory spoke of absolute chance. “Chance” to Einstein was a shorthand way of referring to ignorance, to

a gap in a theory, to some experimental interference that had not yet been taken into account.

Wolfgang Pauli, another of the physicists who helped to develop quantum theory, put the counterargument most forcefully when he suggested that physics had to come to terms with what he called “the irrational in matter.” Pauli himself had many conversations with the psychologist Carl Jung, who had discovered what Pauli termed an “objective level” to the unconscious. It is objective because this collective unconscious is universal and lies beyond any personal and individual events in a person’s life. Likewise, Pauli suggested that just as mind had been discovered to have an objective level, so too would matter be found to have a subjective aspect. One feature of this was what Pauli called the “irrational” behavior of matter. Irrationality, for Pauli, included quantum chance, events that occur outside the limits of causality and rational physical law.

The gap between Pauli’s irrationality of matter and Einstein’s objective reality is very wide. What made this gap unbridgeable was an even more radical uncertainty—whether or not an underlying reality exists at the quantum level, whether or not there is any reality independent of an act of observation.

## *Heisenberg’s Uncertainty Principle*

This disappearance of an ultimate reality has its seed in Werner Heisenberg’s famous uncertainty principle. When Heisenberg discovered quantum mechanics he noticed that his mathematical formulation dictated that certain properties, such as the speed and position of an electron, couldn’t be simultaneously known for certain. This discovery was then expressed as Heisenberg’s uncertainty principle.

When astronomers want to predict the path of a comet all they need to do is measure its speed and position at one instance. Given the force of gravity and Newton’s laws of motion, it is a simple matter to plug speed and position into the equations and plot out the exact path of that comet for centuries to come. But when it comes to an electron, things are profoundly different. An experimenter can pin down its

position, or its speed, but never both at the same time without a measure of uncertainty or ambiguity creeping in. Quantum theory dictates that no matter how refined are the measurements, the level of uncertainty can never be reduced.

How does this come about? It turns out to be a direct result of Max Planck's discovery that energy, in all its forms, is always present in discrete packets called quanta. This means a quantum cannot be split into parts. It can't be divided or shared. The quantum world is a discrete world. Either you have a quantum or you don't. You can't have half or 99 percent of a quantum.

This fact has a staggering implication when it comes to our knowledge of the atomic world. Scientists learn about the world around them by making observations and taking measurements. They ask: How bright is a star? How hot is the sun? How heavy is Newton's apple? How fast is a meteor?

## *Quantum Participation*

Whenever a measurement is made something is recorded in some way. If no record were created, if no change had occurred, then no measurement would have been made or registered. This may not be obvious at first sight so let's do an experiment: Measure the temperature of a beaker of water. Put a thermometer in the water and register how high the mercury rises. For this to happen some of the heat of the water must have been used to heat up and expand the mercury in the thermometer. In other words, an exchange of energy between the water and the thermometer is necessary before a measurement can be said to have been recorded.

What about the position or the speed of a rocket? Electromagnetic waves are bounced off the rocket, picked up on a radar dish, and processed electronically. From the returned signals it is a simple matter to determine the rocket's position. These same signals can also be used to find out how fast the rocket is traveling—the technique is to use what is known as the Doppler shift—a slight change in frequency of the reflected signal. (This Doppler shift is the same effect you hear as a

change in pitch of the siren as an ambulance or police car approaches and then speeds off into the distance.) Because the radar radiation has bounced off the rocket this means that an exchange of energy has taken place. Of course in this case the amount of energy is entirely negligible when compared with the energy of the traveling rocket.

No matter what example you think of, whenever a measurement is made some exchange of energy takes place—the rise or fall of mercury in a thermometer, a Geiger counter's clicks, the swing of a meter, electrical signals from a probe that write onto a computer's memory, the movement of a pen on a chart. In our large-scale world we don't bother about the size of the energy exchange. The amount of heat that is needed to push mercury up a thermometer is too small to be concerned with when compared to the energy of a pan of boiling water. Moreover it is always possible for measurements to be refined and any perturbing effects calculated and compensated for.

Things are quite different in the quantum world. To make a quantum observation or to register a measurement in any way, at least one quantum of energy must be exchanged between apparatus and quantum object. But because a quantum is indivisible, it cannot be split or divided. At the moment of observation we cannot know if that quantum came from the measuring apparatus or from the quantum object. During the measurement, object and apparatus are irreducibly linked.

As a measurement is being made and registered the quantum object and measuring apparatus form an indissoluble whole. The observer and the observed are one. The only way they could be separated is if we could cut a quantum into two parts—one part remaining with the measuring apparatus and the other with the quantum object. But this cannot be done. So the measuring apparatus and quantum system are wedded together by at least one quantum. What's more, the energy of this quantum is not negligible when compared with the energy of the quantum system.

This means that every time scientists try to observe the quantum world they disturb it. And because at least one quantum of energy must always be involved, there is no way in which the size of this disturbance can be reduced. Our acts of observing the universe, our attempts to gather knowledge, are no longer strictly objective because in seeking to

know the universe we act to disturb it. Science prides itself on objectivity, but now Nature is telling us that we will never see a pure, pristine, and objective quantum world. In every act of observation the observing subject enters into the cosmos and disturbs it in an irreducible way.

Science is like photographing a series of close-ups with your back to the sun. No matter which way you move, your shadow always falls across the scene you photograph. No matter what you do, you can never efface yourself from the photographed scene.

The physicist John Wheeler used the metaphor of a plate glass window. For centuries science viewed the universe objectively, as if we were separated from it by a pane of plate glass. Quantum theory smashed that glass forever. We have reached in to touch the cosmos. Instead of being the objective observers of the universe we have become participators.

## *Heisenberg's Microscope*

Our story of quantum strangeness has not yet ended. There is one further step to take—a step that Einstein could never accept and which has implications for the very nature of reality. It is a step that arose in a dispute between Bohr and Heisenberg over the interpretation of the uncertainty principle.

In the early days of quantum theory Werner Heisenberg tried to explain the origins of uncertainty much as I have done in the preceding text, by analogy with the way radar is used to ascertain the position and speed of a rocket. In the large-scale world of rockets and meteors a continuous stream of radar signals is used, but Heisenberg was thinking of an idealized sort of microscope that could be used to study an electron. This microscope would use the minimum amount of disturbance—a single photon, or quantum of light, at a time.

First, a single photon determines the speed of the electron and the result is written down. Next, a single photon determines the position of the electron and that result is written down. But by measuring this position, the electron received an impact by a photon, which changed its speed. Alternatively, in measuring the speed, the impacting photon deflects the electron from its path, thus affecting its position. In other

words, Heisenberg pointed out, as soon as you try to measure position you change the electron's speed, and as soon as you try to measure speed you change the electron's position. There is always an irreducible element of uncertainty involving speed and position.<sup>1</sup>

It is in this way, Heisenberg argued, that uncertainty arises. It is the result of the disturbances we make when we attempt to interrogate the quantum world. Because the quantum is indivisible this uncertainty is totally unavoidable. The French physicist Bernard D'Espagnat coined the term "a veiled reality" for this property. Quantum reality by its very nature, he observed, is veiled and concealed from us. No matter how refined our experiments may be, the ultimate nature of this reality can never be fully revealed.

## *The Disappearance of Quantum Reality*

There the matter stood until Niels Bohr stepped in. While physicists such as Werner Heisenberg, Wolfgang Pauli, Erwin Schrödinger, and Max Born were working at the mathematical formulation of the new theory, Niels Bohr was thinking about what the theory actually meant. For this reason he summoned Heisenberg to Copenhagen and confronted him about the deeper significance of his "microscope experiment."

Bohr argued that Heisenberg's explanation began by assuming the electron actually *has* a position and a speed and that the act of measuring one of these properties disturbs the other. In other words, Bohr claimed that Heisenberg was assuming the existence of a fixed underlying reality; that quantum objects possess properties—just like everyday objects in our own world—and that each act of observation interferes with one of these properties.

He went on to argue that Heisenberg's very starting point was

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<sup>1</sup>Because a quantum is indivisible and shared between observer and observed, physics cannot say if a particular photon was produced by the apparatus, or by the observed electron, or both together. For this reason it is not possible to calculate the effect of perturbations on speed and position and thereby compensate to reduce the uncertainty.

wrong in assuming that the electron *has* intrinsic properties. To say that an electron *has* a position and *has* a speed only makes sense in our large-scale world. Indeed, concepts like causality, spatial position, speed, and path only apply in the physics of the large scale. They cannot be imported into the world of the quantum.

Bohr's argument was so forceful that he actually reduced Heisenberg to tears. Whereas Heisenberg had argued that the act of looking at the universe disturbs quantum properties, Bohr's position was far subtler. Every act of making a measurement, he said, is an act of interrogating the universe. The answer one receives to this interrogation depends on how the question is framed—that is, how the measurement is made. Rather than trying to unveil an underlying quantum property, the properties we observe are in a certain sense the product of the act of measurement itself. Ask a question one way and Nature has been framed into giving a certain answer. Pose the question in another way and the answer will be different. Rather than disturbing the universe, the answer to a quantum measurement is a form of co-creation between observer and observed.

Take, for example, the path of a rocket in the large-scale world. You observe the rocket at point A. Now look away and a moment later glance back and see it at point B. Although you were not looking at the rocket as it sped between A and B, it still makes perfect sense to assume that the rocket was actually somewhere between the two points. You assume that at each instant of time it had a well-defined position and path through space irrespective of the fact that you were not looking at it!

Things are different in the quantum world. An electron can also be observed at point A and then, later, at point B. But in the quantum case one cannot speak of it *having* a path from A to B, nor can one say that when it was not being observed it still *had* a speed and position.

## *Postmodern Reality*

Pauli spoke of the need for physics to confront the subjective levels of matter and come to terms with irrationality in nature. It is as if physics

in the early decades of the twentieth century was anticipating what has become known as postmodernism and “the death of the author.”

Earlier ideas of literature held that a book or poem has an objective quality; it holds the meanings created by the author, and the reader has the responsibility to tease out these meanings during the act of reading. When at school we read a play by Shakespeare or analyzed a poem by Milton, we were told to uncover the various images, metaphors, and figures of speech that act as clues to the underlying meaning intended by the author.

The postmodern approach suggests that reading is more of a creative act in which readers create and generate meanings out of their own experience and history of reading. Likewise the author writes within the context of the whole history of literature and the multiple associations of language. Hence the author is no longer the final voice of authority, the true “onlie begetter.” The reader is no longer just the passive receiver of information but the one who gives the text its life.

When Einstein spoke of the Good Lord he had in mind a notion of authorship similar to that of an earlier period; that is, of someone similar to the author of a Victorian novel. God had created the universe out of nothing and we, as its creatures, could come to understand the divine pattern of creation. Such a pattern was objective and existed independent of our thoughts, wishes, and desires. The extent to which this pattern remained veiled from us was a measure of our human limitations as readers of the divine book of creation.

Bohr and his colleagues in Copenhagen adopted a position close to that of the postmodern reader. The “properties” of the electron are not objective and independently existing, but arise in the act of observation itself. Without this act of observation, or creative “reading,” the “properties” of an electron could not be said to exist as such. This was the origin of the real break between Bohr and Einstein.

Einstein had argued against the notion of absolute chance in quantum theory, although he was ultimately willing to admit that a quantum observation does disturb the universe in an unpredictable way and that the radioactive decay of a nucleus may be totally unpredictable. But he could never give up his belief that the universe has a

definite existence. Even if we disturb the universe when we observe it, he believed, it still has an independent existence. Like an authorial text from the Victorian era, the universe, for Einstein, has a true, independent existence. It may be veiled from us, but nevertheless it still exists. We may not know the particular properties of an electron when we are not observing it, but such properties continue to exist. We may not know where an electron is located at the present moment, but it must have a path as it travels from A to B.

As Einstein put it, the cosmos is constructed of “independent elements of reality.” Admittedly when we try to probe that reality our observations perturb things. But when we are not observing, when we are far away from a quantum system, it must have a true objective reality and it must possess well-defined properties—even if we don’t happen to know what these are.

This was Einstein’s sticking point. This was his most basic belief, that there is an objective reality behind the appearances of the world, even down to the quantum domain. His theory of relativity showed that, although appearances depend upon an observer’s state of motion, behind these appearances stand objective laws of material reality. Provided we do not disturb the universe, it has an existence totally independent of us. He once said to his colleague, Abraham Pais, that he refused to believe that the moon ceased to exist when he was not observing it. But if Bohr were correct, then the universe, for Einstein, simply would no longer make sense.

Over the years, Einstein and Bohr met to debate this very point. Einstein would try to generate an idealized observation (“thought experiment”) that would give sense to his notion of an independent reality. Bohr, in turn, would mull over Einstein’s proposals and ultimately find flaws in the argument.

These “thought experiments” were never intended as actual laboratory experiments but were instead mental exercises used to discover whether some basic principle of physics was being violated. Take for example the issue of Heisenberg’s uncertainty principle, which states that pairs of properties, such as momentum (speed times mass) and position, cannot both be known together with absolute certainty. A related uncertainty involves time and energy. When physicists attempt

to measure the energy of a quantum system over smaller and smaller time intervals this same energy becomes more and more uncertain. For Bohr this ambiguity was basic to the quantum theory, whereas for Einstein, time and energy or position and momentum were objective realities “possessed” by the quantum theory. The only uncertainty, according to Einstein, lay in our inability or lack of ingenuity in measuring the objective properties of such systems.

When Bohr and Einstein met at the Solvay conference in 1930, Einstein presented Bohr with another thought experiment. Suppose, he said, we have a box filled with radiation and a shutter timed to open and close for a split second. The time interval is known with great precision, and in that interval a small amount of energy—a single photon—will escape from the box. Einstein now anticipated Bohr’s position that the shorter the time interval, the more uncertain will be our knowledge of the amount of energy that has escaped. Einstein’s special theory of relativity showed that energy and mass are equivalent, as shown by the formula  $E=mc^2$ . Therefore, if the box is weighed before and after the shutter opens, it will be lighter in the second weighing. This difference in mass gives a precise measure of how much energy has escaped. In this way, an accurate measure of energy is determined within a precise time interval. At this point, Einstein argued that he had demolished Bohr’s claim about fundamental uncertainty.

Bohr had to be equally ingenious, and so he looked in detail at the way the box would be weighed. He posited that, if the box were mounted on a spring balance with the pointer of the balance pointing to zero, energy would escape the box at the moment the shutter opens, and in consequence, the mass of the box would decrease very slightly, and the box would move. As the box moves, so too the clock inside the box moves through the earth’s gravitational field. Einstein’s general theory of relativity tells us that the rate of a clock changes as it moves through a gravitational field. In this way Bohr was able to show that, because of changes in the rate of the clock, the more accurately we attempt to measure energy (via a change in the mass of the box) the greater will be the uncertainty in the time interval when the shutter is open. In this way Heisenberg’s uncertainty was restored and Einstein’s thought experiment was refuted.

Increasingly Einstein's objections were being frustrated by Bohr. Then, in 1931, Einstein and his colleagues Boris Podolsky and Nathan Rosen (EPR) believed they had finally come up with a foolproof example. By taking a quantum system and splitting it exactly in half (say parts A and B), and by having the two halves fly off to opposite ends of the universe, measurements made on A can have absolutely no effect on far-off B. But, because of fundamental conservation laws (the symmetry between the two identical halves) we can deduce some of the properties of B (such as spin or velocity) without ever observing it.

This paper reached Bohr "like a bolt from the blue." He set aside all his other work and repeatedly asked his close colleague Leon Rosenfeld, "What can they mean? Do you understand it?" Finally, six weeks later, Bohr had his refutation of Einstein's argument. "They do it 'smartly,'" he commented on the EPR argument, "but what counts is to do it right."<sup>2</sup>

By now the reader will have gathered that Bohr was an extremely subtle thinker. So subtle, in fact, that physicists still puzzle today about the implications of his ideas. In particular, his answer to the EPR experiment is still being discussed. One stumbling block was Bohr's writing style. As we have already learned, the Danish physicist was a great believer in complementarity, the principle that a single explanation cannot exhaust the richness of experience but rather complementary and even paradoxical explanations must be present. As his long-time colleague Leon Rosenfeld put it, "Whenever he had to write something down, being so anxious about complementarity, he felt that the statement contained in the first part of the sentence had to be corrected by an opposite statement at the end of the sentence."<sup>3</sup>

In the EPR argument, Einstein held to his belief that there must exist "independent elements of reality." He agreed with Bohr that when physicists attempt to measure a quantum system, the act of observa-

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<sup>2</sup>The remarks of Bohr were made to Leon Rosenfeld. John Archibald Wheeler and Wojcieh Hubert Zurek, eds. *Quantum Theory and Measurement* (Princeton, NJ: Princeton University Press, 1983).

<sup>3</sup>Paul Buckley and F. David Peat, eds. *Glimpsing Reality: Ideas in Physics and the Link to Biology* (Toronto: University of Toronto Press, 1996).

tion perturbs that system. However, by observing only one part, A, of a system, when the other part, B, is located far away, no form of interaction—no mechanical force or field of influence—can possibly interfere with B.

Bohr agreed that Einstein had ruled out any mechanical influence on system B; nevertheless, he argued that “the procedure of measurement” has “an essential influence” on the very definition of the physical variables that are to be measured.<sup>4</sup>

With this argument Bohr felt that he had finally put an end to all objections to his “Copenhagen interpretation” of quantum theory. There were no “independent elements of reality,” rather quantum theory displayed the essential wholeness of the universe. It is not a universe put together through a series of quasi-independent elements in interaction; instead what we take for elements or “parts” actually emerge out of the overall dynamics of quantum systems. Properties of a system do not exist “out there,” as it were, but are defined through the various ways in which we approach and observe a system. As Bohr pointed out, the intention or disposition to make a measurement—for example, to collect the apparatus together—determines to some extent which sorts of properties can be measured. In this sense, although a “mechanical” interference between B and the apparatus used to measure A is absent, there is always an *influence*, to use Bohr’s term, on those conditions that define possible outcomes and results.

One interesting contribution to emerge out of this discussion of the EPR paradox was made by John Bell who pointed out that quantum wholeness means that the two parts of the system A and B will continue to be “correlated” even when they are far apart. In no sense does A interact with B; nevertheless (and loosely speaking) B “knows” when a measurement is being performed on A. Or rather, it would be better to say that A and B remain co-related. This co-relationship has since been confirmed by very accurate laboratory experiments.

Bohr felt that his refutation spelled the final death knell to Einstein’s dream of an independent reality. Einstein, for his part, was

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<sup>4</sup>If the reader finds this statement difficult to understand, that particular puzzlement is shared by deep thinkers from theoretical physics and the philosophy of science.

never satisfied. The two men drifted apart to the point where deep communication between them was no longer possible. Their break symbolizes the dislocation in thought that occurred during the twentieth century, a dislocation between causality and chance, between certainty and uncertainty, objective reality and subjective reading. It is a split that remains in physics today as a form of almost schizophrenic thinking. As the physicist Basil Hiley puts it, “physicists give lip service to Bohr and deny Einstein, but most of them end up ignoring what Bohr thought and still think like Einstein.”<sup>5</sup>

## *We Are All Suspended in Language*

No wonder so many working physicists continue to think like Einstein, for Bohr’s mind was extremely subtle. Already he had proposed that the notion of complementarity extends beyond physics into the whole of thought. Now he was questioning the very limitations of the human mind as it seeks to grasp reality.

Until the advent of quantum theory physicists had thought about the universe in terms of models, albeit mathematical ones. A model is a simplified picture of physical reality; one in which, for example, certain contingencies such as friction, air resistance, and so on have been neglected. This model reproduces within itself some essential feature of the universe. While everyday events in nature are highly contingent and depend upon all sorts of external perturbations and contexts, the idealized model aims to produce the essence of phenomena. Apples and cannon balls fly through an idealized space free from air resistance. Balls roll down a perfectly smooth slope in the absence of friction. An electrical current flows through a perfect metal, free from flaws and dislocations. Heat circulates around a perfectly insulated cycle from its source to some machine.

The theories of science are all about idealized models and, in turn, these models give pictures of reality. We shall explore this notion of

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<sup>5</sup>Basil Hiley in conversation with the author.

“pictures of the world” in greater depth when we meet the work of Ludwig Wittgenstein in Chapter 4. For the moment let us examine Bohr’s argument that all these pictures and models are based upon concepts that have evolved out of classical physics. Therefore they will always give rise to paradox and confusion when applied to the quantum world.

Bohr went even further. Physicists may work with measurements, mathematics, and equations but when they meet to discuss the meaning of these equations and describe the work they are doing, they have to speak using the same ordinary language (spoken or written) that we all use. Admittedly they employ a large number of technical terms and equations, but the bulk of these discussions take place in everyday language that evolved amongst human groups who live in the large-scale world and who are of a particular size and lifespan. The human scale of things is vastly different from that of atoms and electrons. As human consciousness evolved so too did notions of position, space, time, and causality. In their most basic form these concepts help us to survive and to explain the world around us. All these “large-scale” notions are so deeply ingrained within our language that it is impossible to carry on a discussion without (subtly and largely unconsciously) using them. But when we speak of the quantum world we find we are employing concepts that simply do not fit. When we discuss our models of reality we are continually importing ideas that are inappropriate and have no real meaning in the quantum domain. It is for this reason that Bohr declared, “We are suspended in language so that we don’t know which is up and which is down.” Our discursive thought always takes place within language, and that language predisposes us to picture the world in a certain way, a way that is incompatible with the quantum world.<sup>6</sup>

As soon as we ask, What is the nature of quantum reality? What is the underlying nature of the world? Is there a reality at the quantum level? we find ourselves entangled in words, pictures, images, models, and ideas from the large-scale world. The result, Bohr pointed out, is

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<sup>6</sup>Wheeler and Zurek. *Op cit.*

confusion and paradox. In the end, it is better to remain silent than to create endless philosophical confusion; maybe this is why the discussions between Bohr and Einstein were doomed to end in silence. What had begun as a discussion of chance and uncertainty developed into a radical transformation of our ideas about the very nature of reality. The deep bond of affection between Einstein and Bohr was insufficient to overcome the growing split in their respective approaches to physics.

## *The Disappearance of Ultimate Reality*

Quantum theory introduced uncertainty into physics; not an uncertainty that arises out of mere ignorance but a fundamental uncertainty about the very universe itself. Uncertainty is the price we pay for becoming participators in the universe. Ultimate knowledge may only be possible for ethereal beings who lie outside the universe and observe it from their ivory towers. But as incarnate beings, we live within the heart of the material world. We are all participators in the world, and the entrance fee we pay is living with a measure of uncertainty.

Uncertainty also exists in another and even more disturbing way, as an uncertainty about the very goal of science and philosophy. From the time of the Greeks, human beings have asked what the world is made of. They attempted to reach, through speculation and experiment, an ultimate ground or ultimate idea upon which all of reality is founded. Twentieth century scientists approached this idea of an ultimate ground by breaking matter into smaller and smaller bits and thereby discovered molecules, atoms, elementary particles, and, along with them, quantum theory.

But then Niels Bohr challenged the ability of science and the human mind to proceed further. He almost seemed to be suggesting that science as we knew it had finally reached a limit and could go no further as a means of enquiry into the nature of reality.<sup>7</sup>

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<sup>7</sup>As a young man, David Bohm debated this issue of reality with Einstein in a series of letters. Einstein firmly held to his belief in an independent reality that is approachable through reason. In reply, Bohm argued that perhaps below our present level of knowledge there lie other levels, as yet unexpected and unexplored.

When the physicist and philosopher Bernard D’Espagnat spoke of the subatomic world as a “veiled reality” he was implying that something real must exist beyond the veil. Again Bohr cautions us against such ideas. We cannot even begin to discuss what lies beyond such a veil, or even that there is a “something” beyond the veil that could be said to have existence. Maybe, in the last analysis, there is no quantum reality. Maybe quantum reality exists only as a concept in our own minds.

And thus we are left with a mystery. Maybe there are no foundations to our world. Maybe there is no final goal toward which science can aim itself. Maybe notions of “existence” and “fundamental levels” are so ephemeral that they will vanish at our touch.

Something analogous occurred with the philosophical movement known as “the death of God,” which has its roots in the writings of Nietzsche. Rather than denying the existence of God, it argued that the human construct, the “idea” of God, the human concept of the divine, had died. In its place that which remains lies beyond the limits

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For 200 years Newton’s physics was sufficient to describe the world—in case after case, it explained the phenomena of nature. It was only with more refined experiments at the end of the nineteenth century that physicists began to detect discrepancies in Newton’s laws and so entered the world of quantum theory. But, as Bohm pointed out, quantum theory is really only needed when one deals with extremely small distances and time intervals or very high energies. For the rest of experience we need no more than classical (that is, Newtonian) physics. This means that our everyday world is extremely insensitive to what is going on beneath it at the atomic level, which is so effectively hidden from ordinary experience that it took 200 years of science to detect it.

But what if another level lies beneath quantum theory? It could take decades upon decades of careful science before such a hidden level is detected. And what if beneath that level there is another, and so on, in perpetuity? Maybe reality is infinite in its subtleties, and science will only be able to penetrate a small distance through its surface. Bohm’s vision was of a science that goes on without limit. Yet at each step the next secret becomes harder and harder to uncover until science itself gives up in exhaustion.

Bohr argued, however, that our ability to enter into some “ultimate reality” of the quantum is doomed to ambiguity and confusion. Even Bohm’s concepts of levels and ideas as fundamental and ultimate are all human-scaled images. They are based, for example, on architectural metaphors. The very moment we open our mouths to ask such questions we prejudice our investigation.

of discourse, concepts, ideas, and language. What remains is untouched and uncontaminated by human thought. It is an absolute mystery.

Is quantum theory telling us that science can only go so far in uncovering the mysteries of existence? Does it mean that at a certain point a further step will only lead to futile confusion? Quantum theory forces us to see the limits of our abilities to make images, to create metaphors, and push language to its ends. As we struggle to gaze into the limits of nature we dimly begin to discern something hidden in the dark shadows. That something consists of ourselves, our minds, our language, our intellect, and our imagination, all of which have been stretched to their limits.