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# HYPER SPACE

'Beautifully written' *The Independent*

OXFORD LANDMARK SCIENCE

# Contents

## Part IV Masters of Hyperspace

# PART 1

# Entering the Fifth Dimension

> But the creative principle resides in mathematics. In a certain sense, therefore, I hold it true that pure thought can grasp reality, as the ancients dreamed.
>
> Albert Einstein

# 1

# Worlds Beyond Space and Time

> I want to know how God created this world. I am not interested in this or that phenomenon. I want to know His thoughts, the rest are details.
>
> Albert Einstein

## The Education of a Physicist

TWO incidents from my childhood greatly enriched my understanding of the world and sent me on course to become a theoretical physicist.

I remember that my parents would sometimes take me to visit the famous Japanese Tea Garden in San Francisco. One of my happiest childhood memories is of crouching next to the pond, mesmerized by the brilliantly colored carp swimming slowly beneath the water lilies.

In these quiet moments, I felt free to let my imagination wander; I would ask myself silly questions that a only child might ask, such as how the carp in that pond would view the world around them. I thought, What a strange world theirs must be!

Living their entire lives in the shallow pond, the carp would believe that their “universe” consisted of the murky water and the lilies. Spending most of their time foraging on the bottom of the pond, they would be only dimly aware that an alien world could exist above the surface. The nature of my world was beyond their comprehension. I was intrigued that I could sit only a few inches from the carp, yet be separated from them by an immense chasm. The carp and I spent our lives in two distinct universes, never entering each other’s world, yet were separated by only the thinnest barrier, the water’s surface.

I once imagined that there may be carp “scientists” living among the fish. They would, I thought, scoff at any fish who proposed that a parallel world could exist just above the lilies. To a carp “scientist,” the only things that were real were what the fish could see or touch. The pond was everything. An unseen world beyond the pond made no scientific sense.

Once I was caught in a rainstorm. I noticed that the pond’s surface was bombarded by thousands of tiny raindrops. The pond’s surface became turbulent, and the water lilies were being pushed in all directions by water waves. Taking shelter from the wind and the rain, I wondered how all this appeared to the carp. To them, the water lilies would appear to be moving around by themselves, without anything pushing them. Since the water they lived in would appear invisible, much like the air and space around us, they would be baffled that the water lilies could move around by themselves.

Their “scientists,” I imagined, would concoct a clever invention called a “force” in order to hide their ignorance. Unable to comprehend that there could be waves on the unseen surface, they would conclude that lilies could move without being touched because a mysterious, invisible entity called a force acted between them. They might give this illusion impressive, lofty names (such as action-at-a-distance, or the ability of the lilies to move without anything touching them).

Once I imagined what would happen if I reached down and lifted one of the carp "scientists" out of the pond. Before I threw him back into the water, he might wiggle furiously as I examined him. I wondered how this would appear to the rest of the carp. To them, it would be a truly unsettling event. They would first notice that one of their "scientists" had disappeared from their universe. Simply vanished, without leaving a trace. Wherever they would look, there would be no evidence of the missing carp in their universe. Then, seconds later, when I threw him back into the pond, the "scientist" would abruptly reappear out of nowhere. To the other carp, it would appear that a miracle had happened.

After collecting his wits, the "scientist" would tell a truly amazing story. "Without warning," he would say, "I was somehow lifted out of the universe (the pond) and hurled into a mysterious nether world, with blinding lights and strangely shaped objects that I had never seen before. The strangest of all was the creature who held me prisoner, who did not resemble a fish in the slightest. I was shocked to see that it had no fins whatsoever, but nevertheless could move without them. It struck me that the familiar laws of nature no longer applied in this nether world. Then, just as suddenly, I found myself thrown back into our universe." (This story, of course, of a journey beyond the universe would be so fantastic that most of the carp would dismiss it as utter poppycock.)

I often think that we are like the carp swimming contentedly in that pond. We live out our lives in our own "pond," confident that our universe consists of only those things we can see or touch. Like the carp, our universe consists of only the familiar and the visible. We smugly refuse to admit that parallel universes or dimensions can exist next to ours, just beyond our grasp. If our scientists invent concepts like forces, it is only because they cannot visualize the invisible vibrations that fill the empty space around us. Some scientists sneer at the mention of higher dimensions because they cannot be conveniently measured in the laboratory.

Ever since that time, I have been fascinated by the possibility of other dimensions. Like most children, I devoured adventure stories in which time travelers entered other dimensions and explored unseen parallel universes, where the usual laws of physics could be conveniently suspended. I grew up wondering if ships that wandered into the Bermuda Triangle mysteriously vanished into a hole in space; I marveled at Isaac Asimov's Foundation Series, in which the discovery of hyperspace travel led to the rise of a Galactic Empire.

A second incident from my childhood also made a deep, lasting impression on me. When I was 8 years old, I heard a story that would stay with me for the rest of my life. I remember my schoolteachers telling the class about a great scientist who had just died. They talked about him with great reverence, calling him one of the greatest scientists in all history. They said that very few people could understand his ideas, but that his discoveries changed the entire world and everything around us. I didn't understand much of what they were trying to tell us, but what most intrigued me about this man was that he died before he could complete his greatest discovery. They said he spent years on this theory, but he died with his unfinished papers still sitting on his desk.

I was fascinated by the story. To a child, this was a great mystery. What was his unfinished work? What was in those papers on his desk? What problem could possibly be so difficult and so important that such a great scientist would dedicate years of his life to its pursuit? Curious, I decided to learn all I could about Albert Einstein and his unfinished theory. I still have warm memories of spending many quiet hours reading every book I could find about this great man and his theories. When I exhausted the books in our local library, I began to scour libraries and bookstores across the city, eagerly searching for more clues. I soon learned that this story was far more exciting than any murder mystery and more important than anything I could ever imagine. I decided that I would try to get to the root of this mystery, even if I had to become a theoretical physicist to do it.

I soon learned that the unfinished papers on Einstein's desk were an attempt to construct what he called the unified field theory, a theory that could explain all the laws of nature, from the tiniest atom to the largest galaxy. However, being a child, I didn't understand that perhaps there was a link between the carp swimming in the Tea Garden and the unfinished papers lying on Einstein's desk. I didn't understand that higher dimensions might be the key to solving the unified field theory.

Later, in high school, I exhausted most of the local libraries and often visited the Stanford University physics library. There, I came across the fact that Einstein's work made possible a new substance called antimatter, which would act like ordinary matter but would annihilate upon contact with matter in a burst of energy. I also read that scientists had built large machines, or "atom smashers," that could produce microscopic quantities of this exotic substance in the laboratory.

One advantage of youth is that it is undaunted by worldly constraints that would ordinarily seem insurmountable to most adults. Not appreciating the obstacles involved, I set out to build my own atom smasher. I studied the scientific literature until I was convinced that I could build what was called a betatron, which could boost electrons to millions of electron volts. (A million electron volts is the energy attained by electrons accelerated by a field of a million volts.)

First, I purchased a small quantity of sodium-22, which is radioactive and naturally emits positrons (the antimatter counterpart of electrons). Then I built what is called a cloud chamber, which makes visible the tracks left by subatomic particles. I was able to take hundreds of beautiful photographs of the tracks left behind by antimatter. Next, I scavenged around large electronic warehouses in the area, assembled the necessary hardware, including hundreds of pounds of scrap transformer steel, and built a 2.3-million-electron-volt betatron in my garage that would be powerful enough to produce a beam of antielectrons. To construct the monstrous magnets necessary for the betatron, I convinced my parents to help me wind 22 miles of cooper wire on the high-school football field. We spent Christmas vacation on the 50-yard line, winding and assembling the massive coils that would bend the paths of the high-energy electrons.

When finally constructed, the 300-pound, 6-kilowatt betatron consumed every ounce of energy my house produced. When I turned it on, I would usually blow every fuse, and the house would suddenly became dark. With the house plunged periodically into darkness, my mother would often shake her head. (I imagined that she probably wondered why she couldn't have a child who played baseball or basketball, instead of building these huge electrical machines in the garage.) I was gratified that the machine successfully produced a magnetic field 20,000 times more powerful than the earth's magnetic field, which is necessary to accelerate a beam of electrons.

## Confronting the Fifth Dimension

Because my family was poor, my parents were concerned that I wouldn't be able to continue my experiments and my education. Fortunately, the awards that I won for my various science projects caught the attention of the atomic scientist Edward Teller. His wife generously arranged for me to receive a 4-year scholarship to Harvard, allowing me to fulfill my dream.

Ironically, although at Harvard I began my formal training in theoretical physics, it was also where my interest in higher dimensions gradually died out. Like other physicists, I began a rigorous and thorough program of studying the higher mathematics of each of the forces of nature separately, in complete isolation from one another. I still remember solving a problem in electrodynamics for my instructor, and then asking him what the solution might look like if space were curved in a higher dimension. He looked at me in a strange way, as if I were a bit cracked. Like others before me, I soon learned to put aside my earlier, childish notions about higher-dimensional space. Hyperspace, I was told, was not a suitable subject of serious study.

I was never satisfied with this disjointed approach to physics, and my thoughts would often drift back to the the carp living in the Tea Garden. Although the equations we used for electricity and magnetism, discovered by Maxwell in the nineteenth century, worked surprisingly well, the equations seemed rather arbitrary. I felt that physicists (like the carp) invented these "forces" to hide our ignorance of how objects can move each other without touching.

In my studies, I learned that one of the great debates of the nineteenth century had been about how light travels through a vacuum. (Light from the stars, in fact, can effortlessly travel trillions upon trillions of miles through the vacuum of outer space.) Experiments also showed beyond question that light is a wave. But if light were a wave, then it would require something to be "waving." Sound waves require air, water waves require water, but since there is nothing to wave in a vacuum, we have a paradox. How can light be a wave if there is nothing to wave? So physicists conjured up a substance called the aether, which filled the vacuum and acted as the medium for light. However, experiments conclusively showed that the "aether" does not exist.*

Finally, when I became a graduate student in physics at the University of California at Berkeley, I learned quite by accident that there was an alternative, albeit controversial, explanation of how light can travel through a vacuum. This alternative theory was so outlandish that I received quite a jolt when I stumbled across it. That shock was similar to the one experienced by many Americans when they first heard that President John Kennedy had been shot. They can invariably remember the precise moment when they heard the shocking news, what they were doing, and to whom they were talking at that instant. We physicists, too, receive quite a shock when we first stumble across Kaluza–Klein theory for the first time. Since the theory was considered to be a wild speculation, it was never taught in graduate school; so young physicists are left to discover it quite by accident in their casual readings.

This alternative theory gave the simplest explanation of light: that it was really a vibration of the fifth dimension, or what used to called the fourth dimension by the mystics. If light could travel through a vacuum, it was because the vacuum itself was vibrating, because the "vacuum" really existed in four dimensions of space and one of time. By adding the fifth dimension, the force of gravity and light could be unified in a startlingly simple way. Looking back at my childhood experiences at the Tea Garden, I suddenly realized that this was the mathematical theory for which I had been looking.

The old Kaluza–Klein theory, however, had many difficult, technical problems that rendered it useless for over half a century. All this, however, has changed in the past decade. More advanced versions of the theory, like supergravity theory and especially superstring theory, have finally eliminated the inconsistencies of the theory. Rather abruptly, the theory of higher dimensions is now being championed in research laboratories around the globe. Many of the world's leading physicists now believe that dimensions beyond the usual four of space and time might exist. This idea, in fact, has become the focal point of intense scientific investigation. Indeed, many theoretical physicists now believe that higher dimensions may be the decisive step in creating a comprehensive theory that unites the laws of nature—a theory of hyperspace.

If it proves to be correct, then future historians of science may well record that one of the great conceptual revolutions in twentieth-century science was the realization that hyperspace may be the key to unlock the deepest secrets of nature and Creation itself.

This seminal concept has sparked an avalanche of scientific research: Several thousand papers written by theoretical physicists in the major research laboratories around the world have been devoted to exploring the properties of hyperspace. The pages of *Nuclear Physics* and *Physics Letters*, two leading scientific journals, have been flooded with articles analyzing the theory. More than 200 international physics conferences have been sponsored to explore the consequences of higher dimensions.

Unfortunately, we are still far from experimentally verifying that our universe exists in higher dimensions. (Precisely what it would take to prove the correctness of the theory and possibly harness the power of hyperspace will be discussed later in this book.) However, this theory has now become firmly established as a legitimate branch of modern theoretical physics. The Institute for Advanced Study at Princeton, for example, where Einstein spent the last decades of his life (and where this book was written), is now one of the active centers of research on higher-dimensional space–time.

Steven Weinberg, who won the Nobel Prize in physics in 1979, summarized this conceptual revolution when he commented recently that theoretical physics seems to be becoming more and more like science fiction.

## Why Can’t We See Higher Dimensions?

These revolutionary ideas seem strange at first because we take for granted that our everyday world has three dimensions. As the late physicist Heinz Pagels noted, “One feature of our physical world is so obvious that most people are not even puzzled by it—the fact that space is three-dimensional.”[1] Almost by instinct alone, we know that any object can be described by giving its height, width, and depth. By giving three numbers, we can locate any position in space. If we want to meet someone for lunch in New York, we say, “Meet me on the twenty-fourth floor of the building at the corner of Forty-second Street and First Avenue.” Two numbers provide us the street corner; and the third, the height off the ground.

Airplane pilots, too, know exactly where they are with three numbers—their altitude and two coordinates that locate their position on a grid or map. In fact, specifying these three numbers can pinpoint any location in our world, from the tip of our nose to the ends of the visible universe. Even babies understand this: Tests with infants have shown that they will crawl to the edge of a cliff, peer over the edge, and crawl back. In addition to understanding “left” and “right” and “forward” and “backward” instinctively, babies instinctively understand “up” and “down.” Thus the intuitive concept of three dimensions is firmly embedded in our brains from an early age.

Einstein extended this concept to include time as the fourth dimension. For example, to meet that someone for lunch, we must specify that we should meet at, say, 12:30 P.M. in Manhattan; that is, to specify an event, we also need to describe its fourth dimension, the *time* at which the event takes place.

Scientists today are interested in going beyond Einstein's conception of the fourth dimension. Current scientific interest centers on the fifth dimension (the spatial dimension beyond time and the three dimensions of space) and beyond. (To avoid confusion, throughout this book I have bowed to custom and called the fourth dimension the *spatial* dimension beyond length, breadth, and width. Physicists actually refer to this as the fifth dimension, but I will follow historical precedent. We will call time the fourth *temporal* dimension.)

How do we see the fourth spatial dimension?

The problem is, we can't. Higher-dimensional spaces are impossible to visualize; so it is futile even to try. The prominent German physicist Hermann von Helmholtz compared the inability to "see" the fourth dimension with the inability of a blind man to conceive of the concept of color. No matter how eloquently we describe "red" to a blind person, words fail to impart the meaning of anything as rich in meaning as color. Even experienced mathematicians and theoretical physicists who have worked with higher-dimensional spaces for years admit that they cannot visualize them. Instead, they retreat into the world of mathematical equations. But while mathematicians, physicists, and computers have no problem solving equations in multidimensional space, humans find it impossible to visualize universes beyond their own.

At best, we can use a variety of mathematical tricks, devised by mathematician and mystic Charles Hinton at the turn of the century, to visualize shadows of higher-dimensional objects. Other mathematicians, like Thomas Banchoff, chairman of the mathematics department at Brown University, have written computer programs that allow us to manipulate higher-dimensional objects by projecting their shadows onto flat, twodimensional computer screens. Like the Greek philosopher Plato, who said that we are like cave dwellers condemned to see only the dim, gray shadows of the rich life outside our caves, Banchoff's computers allow only a glimpse of the shadows of higher-dimensional objects. (Actually, we cannot visualize higher dimensions because of an accident of evolution. Our brains have evolved to handle myriad emergencies in three dimensions. Instantly, without stopping to think, we can recognize and react to a leaping lion or a charging elephant. In fact, those humans who could better visualize how objects move, turn, and twist in three dimensions had a distinct survival advantage over those who could not. Unfortunately, there was no selection pressure placed on humans to master motion in four spatial dimensions. Being able to see the fourth spatial dimension certainly did not help someone fend off a charging saber-toothed tiger. Lions and tigers do not lunge at us through the fourth dimension.)

## The Laws of Nature Are Simpler in Higher Dimensions

One physicist who delights in teasing audiences about the properties of higher-dimensional universes is Peter Freund, a professor of theoretical physics at the University of Chicago's renowned Enrico Fermi Institute. Freund was one of the early pioneers working on hyperspace theories when it was considered too outlandish for mainstream physics. For years, Freund and a small group of scientists dabbled in the science of higher dimensions in isolation; now, however, it has finally become fashionable and a legitimate branch of scientific research. To his delight, he is finding that his early interest is at last paying off.

Freund does not fit the traditional image of a narrow, crusty, disheveled scientist. Instead, he is urbane, articulate, and cultured, and has a sly, impish grin that captivates nonscientists with fascinating stories of fast-breaking scientific discoveries. He is equally at ease scribbling on a blackboard littered with dense equations or exchanging light banter at a cocktail party. Speaking with a thick, distinguished Romanian accent, Freund has a rare knack for explaining the most arcane, convoluted concepts of physics in a lively, engaging style.

Traditionally, Freund reminds us, scientists have viewed higher dimensions with skepticism because they could not be measured and did not have any particular use. However, the growing realization among scientists today is that any three-dimensional theory is "too small" to describe the forces that govern our universe.

As Freund emphasizes, one fundamental theme running through the past decade of physics has been that *the laws of nature become simpler and elegant when expressed in higher dimensions*, which is their natural home. The laws of light and gravity find a natural expression when expressed in higher-dimensional space–time. The key step in unifying the laws of nature is to increase the number of dimensions of space–time until more and more forces can be accommodated. In higher dimensions, we have enough "room" to unify all known physical forces.

Freund, in explaining why higher dimensions are exciting the imagination of the scientific world, uses the following analogy: "Think, for a moment, of a cheetah, a sleek, beautiful animal, one of the fastest on earth, which roams freely on the savannas of Africa. In its natural habitat, it is a magnificent animal, almost a work of art, unsurpassed in speed or grace by any other animal. Now," he continues,

> think of a cheetah that has been captured and thrown into a miserable cage in a zoo. It has lost its original grace and beauty, and is put on display for our amusement. We see only the broken spirit of the cheetah in the cage, not its original power and elegance. The cheetah can be compared to the laws of physics, which are beautiful in their natural setting. The natural habitat of the laws of physics is higher-dimensional space–time. However, we can only measure the laws of physics when they have been broken and placed on display in a cage, which is our three-dimensional laboratory. We only see the cheetah when its grace and beauty have been stripped away.[2]

For decades, physicists have wondered why the four forces of nature appear to be so fragmented—why the "cheetah" looks so pitiful and broken in his cage. The fundamental reason why these four forces seem so dissimilar, notes Freund, is that we have been observing the "caged cheetah." Our three-dimensional laboratories are sterile zoo cages for the laws of physics. But when we formulate the laws in higher-dimensional space–time, their natural habitat, we see their true brilliance and power; the laws become simple and powerful. The revolution now sweeping over physics is the realization that the natural home for the cheetah may be hyperspace.

To illustrate how adding a higher dimension can make things simpler, imagine how major wars were fought by ancient Rome. The great Roman wars, often involving many smaller battlefields, were invariably fought with great confusion, with rumors and misinformation pouring in on both sides from many different directions. With battles raging on several fronts, Roman generals were often operating blind. Rome won its battles more from brute strength than from the elegance of its strategies. That is why one of the first principles of warfare is to seize the high ground—that is, to go *up* into the third dimension, above the twodimensional battlefield. From the vantage point of a large hill with a panoramic view of the battlefield, the chaos of war suddenly becomes vastly reduced. In other words, viewed from the third dimension (that is, from the top of the hill), the confusion of the smaller battlefields becomes integrated into a coherent single picture.

Another application of this principle—that nature becomes simpler when expressed in higher dimensions—is the central idea behind Einstein's special theory of relativity. Einstein revealed time to be the fourth dimension, and he showed that space and time could conveniently be unified in a four-dimensional theory. This, in turn, inevitably led to the unification of all physical quantities measured by space and time, such as matter and energy. He then found the precise mathematical expression for this unity between matter and energy: $E = mc^2$, perhaps the most celebrated of all scientific equations.*

To appreciate the enormous power of this unification, let us now describe the four fundamental forces, emphasizing how different they are, and how higher dimensions may give us a unifying formalism. Over the past 2,000 years, scientists have discovered that all phenomena in our universe can be reduced to four forces, which at first bear no resemblance to one another.

### The Electromagnetic Force

The electromagnetic force takes a variety of forms, including electricity, magnetism, and light itself. The electromagnetic force lights our cities, fills the air with music from radios and stereos, entertains us with television, reduces housework with electrical appliances, heats our food with microwaves, tracks our planes and space probes with radar, and electrifies our power plants. More recently, the power of the electromagnetic force has been used in electronic computers (which have revolutionized the office, home, school, and military) and in lasers (which have introduced new vistas in communications, surgery, compact disks, advanced Pentagon weaponry, and even the check-out stands in groceries). More than half the gross national product of the earth, representing the accumulated wealth of our planet, depends in some way on the electromagnetic force.

### The Strong Nuclear Force

The strong nuclear force provides the energy that fuels the stars; it makes the stars shine and creates the brilliant, life-giving rays of the sun. If the strong force suddenly vanished, the sun would darken, ending all life on earth. In fact, some scientists believe that the dinosaurs were driven to extinction 65 million years ago when debris from a comet impact was blown high into the atmosphere, darkening the earth and causing the temperature around the planet to plummet. Ironically, it is also the strong nuclear force that may one day take back the gift of life. Unleashed in the hydrogen bomb, the strong nuclear force could one day end all life on earth.

### The Weak Nuclear Force

The weak nuclear force governs certain forms of radioactive decay. Because radioactive materials emit heat when they decay or break apart, the weak nuclear force contributes to heating the radioactive rock deep within the earth's interior. This heat, in turn, contributes to the heat that drives the volcanoes, the rare but powerful eruptions of molten rock that reach the earth's surface. The weak and electromagnetic forces are also exploited to treat serious diseases: Radioactive iodine is used to kill tumors of the thyroid gland and fight certain forms of cancer. The force of radioactive decay can also be deadly: It wreaked havoc at Three Mile Island and Chernobyl; it also creates radioactive waste, the inevitable byproduct of nuclear weapons production and commercial nuclear power plants, which may remain harmful for millions of years.

### The Gravitational Force

The gravitational force keeps the earth and the planets in their orbits and binds the galaxy. Without the gravitational force of the earth, we would be flung into space like rag dolls by the spin of the earth. The air we breathe would be quickly diffused into space, causing us to asphyxiate and making life on earth impossible. Without the gravitational force of the sun, all the planets, including the earth, would be flung from the solar system into the cold reaches of deep space, where sunlight is too dim to support life. In fact, without the gravitational force, the sun itself would explode. The sun is the result of a delicate balancing act between the force of gravity, which tends to crush the star, and the nuclear force, which tends to blast the sun apart. Without gravity, the sun would detonate like trillions upon trillions of hydrogen bombs.

The central challenge of theoretical physics today is to unify these four forces into a single force. Beginning with Einstein, the giants of twentieth-century physics have tried and failed to find such a unifying scheme. However, the answer that eluded Einstein for the last 30 years of his life may lie in hyperspace.

## The Quest for Unification

Einstein once said, "Nature shows us only the tail of the lion. But I do not doubt that the lion belongs to it even though he cannot at once reveal himself because of his enormous size."[3] If Einstein is correct, then perhaps these four forces are the "tail of the lion," and the "lion" itself is higher-dimensional space–time. This idea has fueled the hope that the physical laws of the universe, whose consequences fill entire library walls with books densely packed with tables and graphs, may one day be explained by a single equation.

Central to this revolutionary perspective on the universe is the realization that higher-dimensional *geometry* may be the ultimate source of unity in the universe. Simply put, the matter in the universe and the forces that hold it together, which appear in a bewildering, infinite variety of complex forms, may be nothing but different vibrations of hyperspace. This concept, however, goes against the traditional thinking among scientists, who have viewed space and time as a passive stage on which the stars and the atoms play the leading role. To scientists, the visible universe of matter seemed infinitely richer and more diverse than the empty, unmoving arena of the invisible universe of space–time. Almost all the intense scientific effort and massive government funding in particle physics has historically gone to cataloging the properties of subatomic particles, such as "quarks" and "gluons," rather than fathoming the nature of geometry. Now, scientists are realizing that the "useless" concepts of space and time may be the ultimate source of beauty and simplicity in nature.

The first theory of higher dimensions was called *Kaluza–Klein theory*, after two scientists who proposed a new theory of gravity in which light could be explained as vibrations in the fifth dimension. When extended to *N*-dimensional space (where *N* can stand for any whole number), the clumsy-looking theories of subatomic particles dramatically take on a startling symmetry. The old Kaluza–Klein theory, however, could not determine the correct value of *N*, and there were technical problems in describing all the subatomic particles.

A more advanced version of this theory, called *supergravity theory*, also had problems. The recent interest in the theory was sparked in 1984 by physicists Michael Green and John Schwarz, who proved the consistency of the most advanced version of Kaluza–Klein theory, called *superstring theory*, which postulates that all matter consists of tiny vibrating strings. Surprisingly, the superstring theory predicts a precise number of dimensions for space and time: ten.*

The advantage of ten-dimensional space is that we have "enough room" in which to accommodate all four fundamental forces. Furthermore, we have a simple physical picture in which to explain the confusing jumble of subatomic particles produced by our powerful atom smashers. Over the past 30 years, hundreds of subatomic particles have been carefully cataloged and studied by physicists among the debris created by smashing together protons and electrons with atoms. Like bug collectors patiently giving names to a vast collection of insects, physicists have at times been overwhelmed by the diversity and complexity of these subatomic particles. Today, this bewildering collection of subatomic particles can be explained as mere vibrations of the hyperspace theory.

## Traveling Through Space and Time

The hyperspace theory has also reopened the question of whether hyperspace can be used to travel through space and time. To understand this concept, imagine a race of tiny flatworms living on the surface of a large apple. It's obvious to these worms that their world, which they call Appleworld, is flat and two dimensional, like themselves. One worm, however, named Columbus, is obsessed by the notion that Appleworld is somehow finite and curved in something he calls the third dimension. He even invents two new words, *up* and *down*, to describe motion in this invisible third dimension. His friends, however, call him a fool for believing that Appleworld could be bent in some unseen dimension that no one can see or feel. One day, Columbus sets out on a long and arduous journey and disappears over the horizon. Eventually he returns to his starting point, proving that the world is actually curved in the unseen third dimension. His journey proves that Appleworld is curved in a higher unseen dimension, the third dimension. Although weary from his travels, Columbus discovers that there is yet another way to travel between distant points on the apple: By burrowing into the apple, he can carve a tunnel, creating a convenient shortcut to distant lands. These tunnels, which considerably reduce the time and discomfort of a long journey, he calls *wormholes*. They demonstrate that the shortest path between two points is not necessarily a straight line, as he's been taught, but a wormhole.

One strange effect discovered by Columbus is that when he enters one of these tunnels and exits at the other end, he finds himself back in the past. Apparently, these wormholes connect parts of the apple where time beats at different rates. Some of the worms even claim that these wormholes can be molded into a workable time machine.

Later, Columbus makes an even more momentous discovery—his Appleworld is actually not the only one in the universe. It is but one apple in a large apple orchard. His apple, he finds out, coexists with hundreds of others, some with worms like themselves, and some without worms. Under certain rare circumstances, he conjectures, it may even be possible to journey between the different apples in the orchard.

We human beings are like the flatworms. Common sense tells us that our world, like their apple, is flat and three dimensional. No matter where we go with our rocket ships, the universe seems flat. However, the fact that our universe, like Appleworld, is curved in an unseen dimension beyond our spatial comprehension has been experimentally verified by a number of rigorous experiments. These experiments, performed on the path of light beams, show that starlight is bent as it moves across the universe.

## Multiply Connected Universes

When we wake up in the morning and open the window to let in some fresh air, we expect to see the front yard. We do *not* expect to face the towering pyramids of Egypt. Similarly, when we open the front door, we expect to see the cars on the street, not the craters and dead volcanoes of a bleak, lunar landscape. Without even thinking about it, we assume that we can safely open windows or doors without being scared out of our wits. Our world, fortunately, is not a Steven Spielberg movie. We act on a deeply ingrained prejudice (which is invariably correct) that our world is *simply connected*, that our windows and doorways are not entrances to wormholes connecting our home to a far-away universe. (In ordinary space, a lasso of rope can always be shrunk to a point. If this is possible, then the space is called simply connected.

However, if the lasso is placed around the entrance of the wormhole, then it cannot be shrunk to a point. The lasso, in fact, enters the wormhole. Such spaces, where lassos are not contractible, are called *multiply connected.* Although the bending of our universe in an unseen dimension has been experimentally measured, the existence of wormholes and whether our universe is multiply connected or not is still a topic of scientific controversy.)

Mathematicians dating back to Georg Bernhard Riemann have studied the properties of multiply connected spaces in which different regions of space and time are spliced together. And physicists, who once thought this was merely an intellectual exercise, are now seriously studying multiply connected worlds as a practical model of our universe. These models are the scientific analogue of Alice's looking glass. When Lewis Carroll's White Rabbit falls down the rabbit hole to enter Wonderland, he actually falls down a wormhole.

Wormholes can be visualized with a sheet of paper and a pair of scissors: Take a piece of paper, cut two holes in it, and then reconnect the two holes with a long tube (Figure 1.1). As long as you avoid walking into the wormhole, our world seems perfectly normal. The usual laws of geometry taught in school are obeyed. However, if you fall into the wormhole, you are instantly transported to a different region of space and time. Only by retracing your steps and falling back into the wormhole can you return to your familiar world.

## Time Travel and Baby Universes

Although wormholes provide a fascinating area of research, perhaps the most intriguing concept to emerge from this discussion of hyperspace is the question of time travel. In the film *Back to the Future*, Michael J. Fox journeys back in time and meets his parents as teenagers before they were married. Unfortunately, his mother falls in love with *him* and spurns his father, raising the ticklish question of how he will be born if his parents never marry and have children.

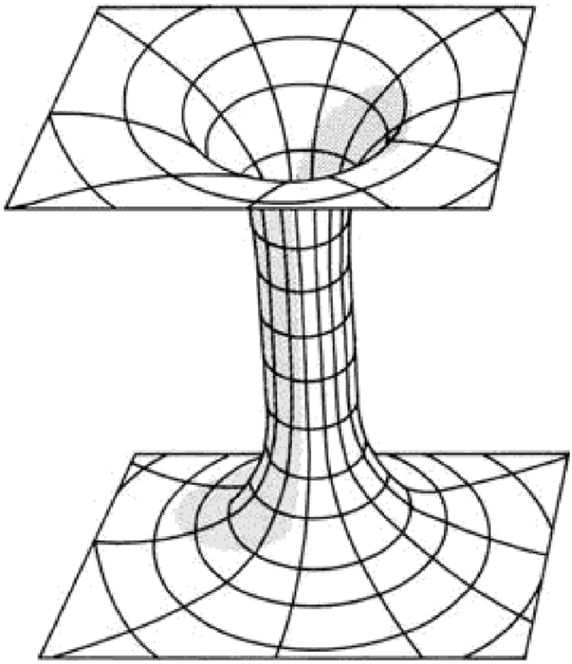

*Figure 1.1. Parallel universes may be graphically represented by two parallel planes. Normally, they never interact with each other. However, at times wormholes or tubes may open up between them, perhaps making communication and travel possible between them. This is now the subject of intense interest among theoretical physicists.*

Traditionally, scientists have held a dim opinion of anyone who raised the question of time travel. Causality (the notion that every effect is preceded, not followed, by a cause) is firmly enshrined in the foundations of modern science. However, in the physics of wormholes, "acausal" effects show up repeatedly. In fact, we have to make strong assumptions in order to prevent time travel from taking place. The main problem is that wormholes may connect not only two distant points in space, but also the future with the past.

In 1988, physicist Kip Thorne of the California Institute of Technology and his collaborators made the astonishing (and risky) claim that time travel is indeed not only possible, but probable under certain conditions. They published their claim not in an obscure "fringe" journal, but in the prestigious *Physical Review Letters*. This marked the first time that reputable physicists, and not crackpots, were scientifically advancing a claim about changing the course of time itself. Their announcement was based on the simple observation that a wormhole connects two regions that exist in different time periods. Thus the wormhole may connect the present to the past. Since travel through the wormhole is nearly instantaneous, one could use the wormhole to go backward in time. Unlike the machine portrayed in H. G. Wells's *The Time Machine*, however, which could hurl the protagonist hundreds of thousands of years into England's distant future with the simple twist of a dial, a wormhole may require vast amounts of energy for its creation, beyond what will be technically possible for centuries to come.

Another bizarre consequence of wormhole physics is the creation of "baby universes" in the laboratory. We are, of course, unable to re-create the Big Bang and witness the birth of our universe. However, Alan Guth of the Massachusetts Institute of Technology, who has made many important contributions in cosmology, shocked many physicists a few years ago when he claimed that the physics of wormholes may make it possible to create a baby universe of our own in the laboratory. By concentrating intense heat and energy in a chamber, a wormhole may eventually open up, serving as an umbilical cord connecting our universe to another, much smaller universe. If possible, it would give a scientist an unprecedented view of a universe as it is created in the laboratory.

## Mystics and Hyperspace

Some of these concepts are not new. For the past several centuries, mystics and philosophers have speculated about the existence of other universes and tunnels between them. They have long been fascinated by the possible existence of other worlds, undetectable by sight or sound, yet coexisting with our universe. They have been intrigued by the possibility that these unexplored, nether worlds may even be tantalizingly close, in fact surrounding us and permeating us everywhere we move, yet just beyond our physical grasp and eluding our senses. Such idle talk, however, was ultimately useless because there was no practical way in which to mathematically express and eventually test these ideas.

Gateways between our universe and other dimensions are also a favorite literary device. Science-fiction writers find higher dimensions to be an indispensable tool, using them as a medium for interstellar travel. Because of the astronomical distances separating the stars in the heavens, science-fiction writers use higher dimensions as a clever shortcut between the stars. Instead of taking the long, direct route to other galaxies, rockets merely zip along in hyperspace by warping the space around them. For instance, in the film *Star Wars*, hyperspace is a refuge where Luke Skywalker can safely evade the Imperial Starships of the Empire. In the television series "Star Trek: Deep Space Nine," a wormhole opens up near a remote space station, making it possible to span enormous distances across the galaxy within seconds. The space station suddenly becomes the center of intense intergalactic rivalry over who should control such a vital link to other parts of the galaxy.

Ever since Flight 19, a group of U.S. military torpedo bombers, vanished in the Caribbean 30 years ago, mystery writers too have used higher dimensions as a convenient solution to the puzzle of the Bermuda Triangle, or Devil's Triangle. Some have conjectured that airplanes and ships disappearing in the Bermuda Triangle actually entered some sort of passageway to another world.

The existence of these elusive parallel worlds has also produced endless religious speculation over the centuries. Spiritualists have wondered whether the souls of departed loved ones drifted into another dimension. The seventeenth-century British philosopher Henry More argued that ghosts and spirits did indeed exist and claimed that they inhabited the fourth dimension. In *Enchiridion Metaphysicum* (1671), he argued for the existence of a nether realm beyond our tangible senses that served as a home for ghosts and spirits.

Nineteenth-century theologians, at a loss to locate heaven and hell, pondered whether they might be found in a higher dimension. Some wrote about a universe consisting of three parallel planes: the earth, heaven, and hell. God himself, according to the theologian Arthur Willink, found his home in a world far removed from these three planes; he lived in infinite-dimensional space.

Interest in higher dimensions reached its peak between 1870 and 1920, when the "fourth dimension" (a spatial dimension, different from what we know as the fourth dimension of time) seized the public imagination and gradually cross-fertilized every branch of the arts and sciences, becoming a metaphor for the strange and mysterious. The fourth dimension appeared in the literary works of Oscar Wilde, Fyodor Dostoyevsky, Marcel Proust, H. G. Wells, and Joseph Conrad; it inspired some of the musical works of Alexander Scriabin, Edgard Varèse, and George Antheil. It fascinated such diverse personalities as psychologist William James, literary figure Gertrude Stein, and revolutionary socialist Vladimir Lenin.

The fourth dimension also inspired the works of Pablo Picasso and Marcel Duchamp and heavily influenced the development of Cubism and Expressionism, two of the most influential art movements in this century. Art historian Linda Dalrymple Henderson writes, "Like a Black Hole, 'the fourth dimension' possessed mysterious qualities that could not be completely understood, even by the scientists themselves. Yet, the impact of 'the fourth dimension' was far more comprehensive than that of Black Holes or any other more recent scientific hypothesis except Relativity Theory after 1919."[5]

Similarly, mathematicians have long been intrigued by alternative forms of logic and bizarre geometries that defy every convention of common sense. For example, the mathematician Charles L. Dodgson, who taught at Oxford University, delighted generations of schoolchildren by writing books—as Lewis Carroll—that incorporate these strange mathematical ideas. When Alice falls down a rabbit hole or steps through the looking glass, she enters Wonderland, a strange place where Cheshire cats disappear (leaving only their smile), magic mushrooms turn children into giants, and Mad Hatters celebrate "unbirthdays." The looking glass somehow connects Alice's world with a strange land where everyone speaks in riddles and common sense isn't so common.

Some of the inspiration for Lewis Carroll's ideas most likely came from the great nineteenth-century German mathematician Georg Bernhard Riemann, who was the first to lay the mathematical foundation of geometries in higher-dimensional space. Riemann changed the course of mathematics for the next century by demonstrating that these universes, as strange as they may appear to the layperson, are completely self-consistent and obey their own inner logic. To illustrate some of these ideas, think of stacking many sheets of paper, one on top of another. Now imagine that each sheet represents an entire world and that each world obeys its own physical laws, different from those of all the other worlds. Our universe, then, would not be alone, but would be one of many possible parallel worlds. Intelligent beings might inhabit some of these planes, completely unaware of the existence of the others. On one sheet of paper, we might have Alice's bucolic English countryside. On another sheet might be a strange world populated by mythical creatures in the world of Wonderland.

Normally, life proceeds on each of these parallel planes independent of the others. On rare occasions, however, the planes may intersect and, for a brief moment, tear the fabric of space itself, which opens up a hole—or gateway—between these two universes. Like the wormhole appearing in "Star Trek: Deep Space Nine," these gateways make travel possible between these worlds, like a cosmic bridge linking two different universes or two points in the same universe (Figure 1.2). Not surprisingly, Carroll found children much more open to these possibilities than adults, whose prejudices about space and logic become more rigid over time. In fact, Riemann's theory of higher dimensions, as interpreted by Lewis Carroll, has become a permanent part of children's literature and folklore, giving birth to other children's classics over the decades, such as Dorothy's Land of Oz and Peter Pan's Never Never Land.

Without any experimental confirmation or compelling physical motivation, however, these theories of parallel worlds languished as a branch of science. Over 2 millennia, scientists have occasionally picked up the notion of higher dimensions, only to discard it as an untestable and therefore silly idea. Although Riemann's theory of higher geometries was mathematically intriguing, it was dismissed as clever but useless. Scientists willing to risk their reputations on higher dimensions soon found themselves ridiculed by the scientific community. Higher-dimensional space became the last refuge for mystics, cranks, and charlatans.

In this book, we will study the work of these pioneering mystics, mainly because they devised ingenious ways in which a nonspecialist could "visualize" what higher-dimensional objects might look like. These tricks will prove useful to understand how these higher-dimensional theories may be grasped by the general public.

By studying the work of these early mystics, we also see more clearly what was missing from their research. We see that their speculations lacked two important concepts: a physical and a mathematical principle. From the perspective of modern physics, we now realize that the missing *physical* principle is that hyperspace simplifies the laws of nature, providing the possibility of unifying all the forces of nature by purely geometric arguments. The missing *mathematical* principle is called *field theory*, which is the universal mathematical language of theoretical physics.

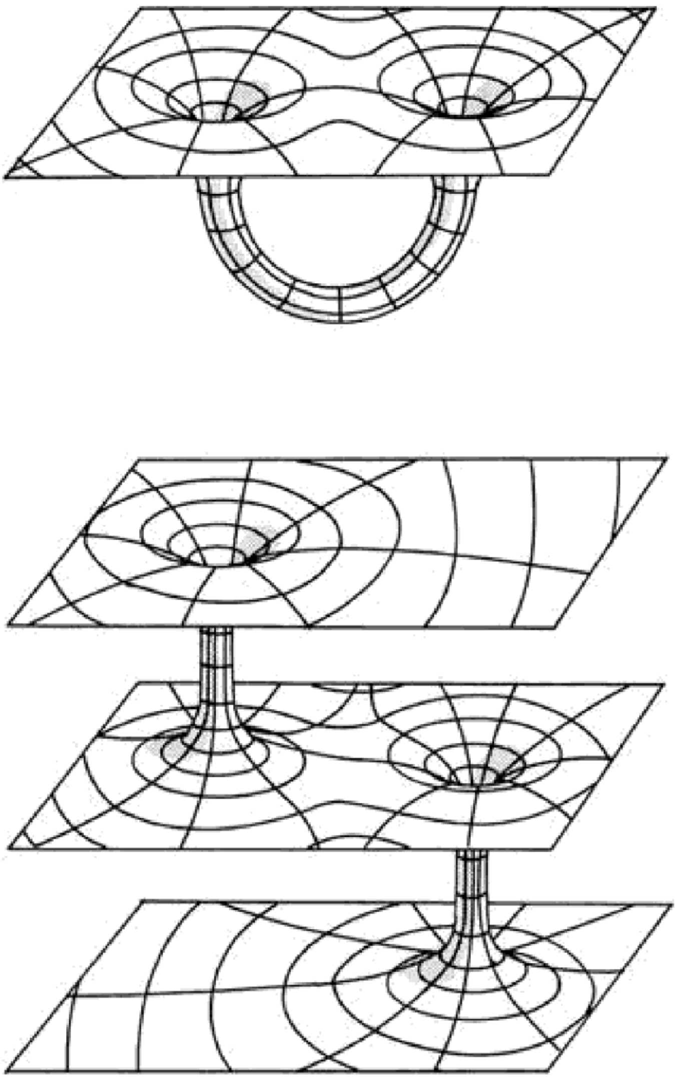

*Figure 1.2. Wormholes may connect a universe with itself, perhaps providing a means of interstellar travel. Since wormholes may connect two different time eras, they may also provide a means for time travel. Wormholes may also connect an infinite series of parallel universes. The hope is that the hyperspace theory will be able to determine whether wormholes are physically possible or merely a mathematical curiosity.*

## Field Theory: The Language of Physics

Fields were first introduced by the great nineteenth-century British scientist Michael Faraday. The son of a poor blacksmith, Faraday was a self-taught genius who conducted elaborate experiments on electricity and magnetism. He visualized "lines of force" that, like long vines spreading from a plant, emanated from magnets and electric charges in all directions and filled up all of space. With his instruments, Faraday could measure the strength of these lines of force from a magnetic or an electric charge at any point in his laboratory. Thus he could assign a series of numbers (the strength and direction of the force) to that point (and any point in space). He christened the totality of these numbers at any point in space, treated as a single entity, a field. (There is a famous story concerning Michael Faraday. Because his fame had spread far and wide, he was often visited by curious bystanders. When one asked what his work was good for, he answered, "What is the use of a child? It grows to be a man." One day, William Gladstone, then Chancellor of the Exchequer, visited Faraday in his laboratory. Knowing nothing about science, Gladstone sarcastically asked Faraday what use the huge electrical contraptions in his laboratory could possibly have for England. Faraday replied, "Sir, I know not what these machines will be used for, but I am sure that one day you will tax them." Today, a large portion of the total wealth of England is invested in the fruit of Faraday's labors.)

Simply put, a *field* is a collection of numbers defined at every point in space that completely describes a force at that point. For example, three numbers at each point in space can describe the intensity and direction of the magnetic lines of dimensions, the field equations of the subatomic world and gravitation are difficult to unify. The advantage of the hyperspace theory is that the Yang–Mills field, Maxwell's field, and Einstein's field can all be placed comfortably within the hyperspace field. We see that these fields fit together precisely within the hyperspace field like pieces in a jigsaw puzzle. The other advantage of field theory is that it allows us to calculate the precise energies at which we can expect space and time to form wormholes. Unlike the ancients, therefore, we have the mathematical tools to guide us in building the machines that may one day bend space and time to our whims.

## The Secret of Creation

Does this mean that big-game hunters can now start organizing safaris to the Mesozoic era to bag large dinosaurs? No. Thorne, Guth, and Freund will all tell you that the energy scale necessary to investigate these anomalies in space is far beyond anything available on earth. Freund reminds us that the energy necessary to probe the tenth dimension is a quadrillion times larger than the energy that can be produced by our largest atom smasher.

Twisting space–time into knots requires energy on a scale that will not be available within the next several centuries or even millennia—if ever. Even if all the nations of the world were to band together to build a machine that could probe hyperspace, they would ultimately fail. And, as Guth points out, the temperatures necessary to create a baby universe in the laboratory is 1,000 trillion trillion degrees, far in excess of anything available to us. In fact, that temperature is much greater than anything found in the interior of a star. So, although it is possible that Einstein's laws and the laws of quantum theory might allow for time travel, this is not within the capabilities of earthlings like us, who can barely escape the feeble gravitational field of our own planet. While we can marvel at the implications of wormhole research, realizing its potential is strictly reserved for advanced extraterrestrial civilizations.

There was only one period of time when energy on this enormous scale was readily available, and that was at the instant of Creation. In fact, the hyperspace theory cannot be tested by our largest atom smashers because the theory is really a theory of Creation. Only at the instant of the Big Bang do we see the full power of the hyperspace theory coming into play. This raises the exciting possibility that the hyperspace theory may unlock the secret of the origin of the universe.

Introducing higher dimensions may be essential for prying loose the secrets of Creation. According to this theory, before the Big Bang, our cosmos was actually a perfect ten-dimensional universe, a world where interdimensional travel was possible. However, this ten-dimensional world was unstable, and eventually it "cracked" in two, creating two separate universes: a four- and a six-dimensional universe. The universe in which we live was born in that cosmic cataclysm. Our four-dimensional universe expanded explosively, while our twin six-dimensional universe contracted violently, until it shrank to almost infinitesimal size. This would explain the origin of the Big Bang. If correct, this theory demonstrates that the rapid expansion of the

# Index