Hyperspace – A Scientific Odyssey

A look at the higher dimensions

Do higher dimensions exist? Are there unseen worlds just beyond our reach, beyond the normal laws of physics? Although higher dimensions have historically been the exclusive realm of charlatans, mystics, and science fiction writers, many serious theoretical physicists now believe that higher dimensions not only exist, but may also explain some of the deepest secrets of nature. Although we stress that there is at present no experimental evidence for higher dimensions, in principle they may solve the ultimate problem in physics: the final unification of all physical knowledge at the fundamental level.

My own fascination with higher dimensions began early in childhood. One of my happiest childhood memories was crouching next to the pond at the famed Japanese Tea Garden in San Francisco, mesmerized by the brilliantly colored carp swimming slowly beneath the water lilies. In these quiet moments, I would ask myself a silly question that a only child might ask: how would the carp in that pond view the world around them? Spending their entire lives at the bottom of the pond, the carp would believe that their “universe” consisted of the water and the lilies; they would only be dimly aware that an alien world could exist just above the surface. My world was beyond their comprehension. I was intrigued that I could sit only a few inches from the carp, yet we were separated by an immense chasm. I concluded that if there were any “scientists” among the carp, they would scoff at any fish who proposed that a parallel world could exist just above the lilies. An unseen world beyond the pond made no scientific sense. Once I imagined what would happen if I reached down and suddenly grabbed one of the carp “scientists” out of the pond. I wondered, how would this appear to the carp? The startled carp “scientist” would tell a truly amazing story, being somehow lifted out of the universe (the pond) and hurled into a mysterious nether world, another dimension with blinding lights and strange-shaped objects that no carp had ever seen before. The strangest of all was the massive creature responsible for this outrage, who did not resemble a fish in the slightest. Shockingly, it had no fins whatsoever, but nevertheless could move without them. Obviously, the familiar laws of physics no longer applied in this nether world!

The Theory of Everything

Sometimes I believe that we are like the carp living contently on the bottom of that pond; we live our lives blissfully ignorant of other worlds that might co-exist with us, laughing at any suggestion of parallel universes.

All this has changed rather dramatically in the past few years. The theory of higher dimensional space may now become the central piece in unlocking the origin of the universe. At the center of this conceptual revolution is the idea that our familiar three dimensional universe is “too small” to describe the myriad forces governing our universe. To describe our physical world, with its almost infinite variety of forms, requires entire libraries overflowing with mountains of technical journals and stacks of obscure, learned books. The ultimate goal of physics, some believe, is to have a single equation or expression from which this colossal volume of information can be derived from first principles. Today, many physicists believe that we have found the “unified field theory” which eluded Einstein for the last thirty years of his life. Although the theory of higher dimensional space has not been verified (and, we shall see, would be prohibitively expensive to prove experimentally), almost 5,000 papers, at last count, have been published in the physics literature concerning higher dimensional theories, beginning with the pioneering papers of Theodore Kaluza and Oskar Klein in the 1920’s and 30s, to the supergravity theory of the 1970s, and finally to the superstring theory of the 1980s and 90s. In fact, the superstring theory, which postulates that matter consists of tiny strings vibrating in hyperspace, predicts the precise number of dimensions of space and time: 10.

Why Can’t we See the Fourth Dimension?

To understand these higher dimensions, we remember that it takes three numbers to locate every object in the universe, from the tip of your nose to the ends of the world. For example, if you want to meet some friends in Manhattan, you tell them to meet you at the building at the corner of 42nd street and 5th avenue, on the 37th floor. It takes two numbers to locate your position on a map, and one number to specify the distance above the map. It thus takes three numbers to specify the location of your lunch. (If we meet our friends at noon, then it takes four numbers to specify the space and time of the meeting.)

However, try as we may, it is impossible for our brains to visualize the fourth spatial dimension. Computers, of course, have no problem working in N dimensional space, but spatial dimensions beyond three simply cannot be conceptualized by our feeble brains. (The reason for this unfortunate accident has to do with biology, rather than physics. Human evolution put a premium on being able to visualize objects moving in three dimensions. There was a selection pressure placed on humans who could dodge lunging saber tooth tigers or hurl a spear at a charging mammoth. Since tigers do not attack us in the fourth spatial dimension, there simply was no advantage in developing a brain with the ability to visualize objects moving in four dimensions.)

Meeting a Higher Dimensional Being

To understand some of the mind-bending features of higher dimensions, imagine a two-dimensional world, called Flat land (after Edwin A. Abbott’s celebrated novel) that resembles a world existing on a flat table-top. If one of the Flatlanders becomes lost, we can quickly scan all of Flatland, peering directly inside houses, buildings, and even concealed places. If one of the Flatlanders becomes sick, we can reach directly into their insides and per form surgery, without ever cutting their skin. If one of the Flatlanders is incarcerated in jail (which is a circle enclosing the Flatlander) we can simply peel the person off from Flatland into the third dimension and place the Flatlander back somewhere else. If we become more ambitious and stick our fingers and arms through Flatland, the Flatlanders would only see circles of flesh that hover around them, constantly changing shape and merging into other circles. And lastly, if we fling a Flatlander into our three dimensional world, the Flatlander can only see two dimensional cross sections of our world, i.e. a phantasmagoria of circles, squares, etc. which constantly change shape and merge (see fig. 1 and 2). Now imagine that we are "three dimensional Flatlanders" being visited by a higher dimensional being. If we became lost, a higher dimensional being could scan our entire universe all at once, peering directly into the most tightly sealed hiding places. If we became sick, a higher dimensional being could reach into our insides and perform surgery without ever cutting our skin. If we were in a maximum-security, escape-proof jail, a higher dimensional being could simply "yank" us into a higher dimension and redeposit us back somewhere else. If higher dimensional beings stick their "fingers" into our universe, they would appear to us to be blobs of flesh which float above us and constantly merge and split apart. And lastly, if we are flung into hyperspace, we would see a collection of spheres, blobs, and polyhedra which suddenly appear, constantly change shape and color, and then mysteriously disappear. Higher dimensional people, therefore, would have powers similar to a god: they could walk through walls, disappear and reappear at will, reach into the strongest steel vaults, and see through buildings. They would be omniscient and omnipotent. Not surprisingly, speculation about higher dimensions has sparked enormous literary and artistic interest over the last hundred years.

Mystics and Mathematics

Fyodor Dostoyevsky, in The Brothers Karamazov, had his protagonist Ivan Karamazov speculate on the existence of higher dimensions and non-Euclidean geometries during a discussion on the existence of God. In H. G. Wells' The Invisible Man, the source of invisibility was his ability to manipulate the fourth dimension. Oscar Wilde even refers to the fourth dimension in his play The Canterville Ghost as the homeworld for ghosts.

The fourth dimension also appears in the literary works of Marcel Proust and Joseph Conrad; it inspired some of the musical works of Alexander Scriabin, Edgar Varege, and George Antheil. It fascinated such diverse personalities as the psychologist William James, literary figure Gertrude Stein, and revolutionary socialist Vladimir Lenin. Lenin even waged a polemic on the N-th dimension with philosopher Ernst Mach in his Materialism and Empirio-Criticism. Lenin praised Mach, who "has raised the very important and useful question of a space of n-dimensions as a conceivable space," but then took him to task by insisting that the Tsar could only be overthrown in the third dimension.

Artists have been particularly interested in the fourth dimension because of the possibilities of discovering new laws of perspective. In the Middle Ages, religious art was distinctive for its deliberate lack of perspective. Serfs, peasants, and kings were depicted as if they were flat, much the way children draw people. Since God was omnipotent and could therefore see all parts of our world equally, art had to reflect His point of view, so the world was painted two-dimensionally. Renaissance art was a revolt against this flat God- centered perspective. Sweeping landscapes and realistic, three dimensional people were painted from the point of view of a person's eye, with the lines of perspective vanishing into the horizon. Renaissance art reflected the way the human eye viewed the world, from the singular point of view of the observer. In other words, Renaissance art discovered the third dimension. With the beginning of the machine age and capitalism, the artistic world revolted against the cold materialism that seemed to dominate industrial society. To the Cubists, positivism was a straitjacket that confined us to what could be measured in the laboratory, suppressing the fruits of our imagination. They asked: Why must art be clinically "realistic?" This Cubist "revolt against perspective" seized the fourth dimension because it touched the third dimension from all possible perspectives. Simply put, Cubist art embraced the fourth dimension. Picasso's paintings are a splendid example, showing a clear rejection of three dimensional perspective, with women's faces viewed simultaneously from several angles. Instead of a single point-of-view, Picasso's paintings show multiple perspectives, as if they were painted by a being from the fourth dimension, able to see all perspectives simultaneously. As art historian Linda Henderson has written, "the fourth dimension and non-Euclidean geometry emerge as among the most important themes unifying much of modern art and theory."

Unifying the Four Forces

Historically, physicists dismissed the theory of higher dimensions because they could never be measured, nor did they have any particular use. But to understand how adding higher dimensions can, in fact, simplify physical problems, consider the following example. To the ancient Egyptians, the weather was a complete mystery. What caused the seasons? Why did it get warmer as they traveled south? The weather was impossible to explain from the limited vantage point of the ancient Egyptians, to whom the earth appeared flat, like a two-dimensional plane.

But now imagine sending the Egyptians in a rocket into outer space, where they can see the earth as simple and whole in its orbit around the sun. Suddenly, the answers to these questions become obvious. From outer space, it is clear that the earth tilts about

23 degrees on its axis in its orbit around the sun. Because of this tilt, the northern hemisphere receives much less sunlight during one part of its orbit than during another part. Hence we have winter and summer. And since the equator receives more sunlight on the average than the northern or southern polar regions, it becomes warmer as we approach the equator.

In summary, the rather obscure laws of the weather are easy to understand once we view the earth from space. Thus, the solution to the problem is to go up into space, into the third dimension. Facts that were impossible to understand in a flat world suddenly become obvious when viewing a unified picture of a three dimensional earth.

The Four Fundemental Forces

Similarly, the current excitement over higher dimensions is that they may hold the key to the unification of all known forces. The culmination of 2,000 years of painstaking observation is the realization that that our universe is governed by four fundamental forces. These four forces, in turn, may be unified in higher dimensional space. Light, for example, may be viewed simply as vibrations in the fifth dimension. The other forces of nature may be viewed as vibrations in increasingly higher dimensions. At first glance, however, the four fundamental forces seem to bear no resemblance to each other. They are:

Gravity is the force which keeps our feet anchored to the spinning earth and binds the solar system and the galaxies together. Without gravity, we would be immediately flung into outer space at l,000 miles per hour. Furthermore, without gravity holding the sun together, it would explode in a catastrophic burst of energy. Electro-magnetism is the force which lights up our cities and energizes our household appliances. The electronic revolution, which has given us the light bulb, TV, the telephone, computers, radio, radar, microwaves, light bulbs, and dishwashers, is a byproduct of the electro-magnetic force.

The strong nuclear force is the force which powers the sun. Without the nuclear force, the stars would flicker out and the heavens would go dark. The nuclear force not only makes life on earth possible, it is also the devastating force unleashed by a hydrogen bomb, which can be compared to a piece of the sun brought down to earth. The weak force is the force responsible for radio active decay involving electrons. The weak force is harnessed in modern hospitals in the form of radioactive tracers used in nuclear medicine. The weak force also wrecked havoc at Chernobyl. Historically, whenever scientists unraveled the secrets of one of the four fundamental forces, this irrevocably altered the course of modern civilization, from the mastery of mechanics and Newtonian physics in the 1700s, to the harnessing of the electro-magnetism in the 1800s, and finally to the unlocking of the nuclear force in the 1900s. In some sense, some of the greatest breakthroughs in the history of science can be traced back to the gradual understanding of these four fundamental forces. Some have even claimed that the progress of the last 2,000 years of science can be understood as the successive mastery of these four fundamental forces. Given the importance of these four fundamental forces, the next question is: can they be united into one super force? Are they but the manifestations of a deeper reality? Given the fruitless search that has stumped the world's Nobel Prize winners for half a century, most physicists agree that the Theory of Everything must be a radical departure from everything that has been tried before. For example, Niels Bohr, founder of the modern atomic theory, once listened to Wolf gang Pauli's explanation of his version of the unified field theory. In frustration, Bohr finally stood up and said, "We are all agreed that your theory is absolutely crazy. But what divides us is whether your theory is crazy enough."

Today, however, after decades of false starts and frustrating dead ends, many of the world's leading physicists think that they have finally found the theory "crazy enough" to be the unified field theory. There is widespread belief (although certainly not unanimous by any means) in the world's major re search laboratories that we have at last found the Theory of Everything.

Field Theory in Higher Dimension

To see how higher dimensions helps to unify the laws of nature, physicists use the mathematical device called "field theory." For example, the magnetic field of a bar magnet resembles a spider's web which fills up all of space. To describe the magnetic field, we introduce the field, a series of numbers defined at each point in space which describes the intensity and direction of the force at that point. James Clerk Maxwell, in the last century, proved that the electro-magnetic force can be described by four numbers at each point in four dimensional space-time (labeled by A_1, A_2, A_3, A_4). These four numbers, in turn, obey a set of equations (called Maxwell's field equations).

For the gravitational force, Einstein showed that the field requires a total of 10 numbers at each point in four dimensions. These 10 numbers can be assembled into the array shown in fig. 3. (Since $g_{12} = g_{21}$, only 10 of the 16 numbers contained within the array are independent.) The gravitational field, in turn, obey Einstein's field equations. The key idea of Theodore Kaluza in the 1920s was to write down a five dimensional theory of gravity. In five dimensions, the gravitational field has 15 independent numbers, which can be arranged in a five dimensional array (see fig.4). Kaluza then re-defined the 5th column and row of the gravitation al field to be the electromagnetic field of Maxwell. The truly miraculous feature of this construction is that the five dimensional theory of gravity reduces down precisely to Einstein's original theory of gravity plus Maxwell's theory of light. In other words, by adding the fifth dimension, we have trivially unified light with gravity. In other words, light is now viewed as vibrations in the fifth dimension. In five dimensions, there is “enough room” to unify both gravity and light.

This trick is easily extended. For example, if we generalize the theory to N dimensions, then the N dimensional gravitational field can be split-up into the following pieces (see fig. 5). Now, out pops a generalization of the electromagnetic field, called the “Yang-Mills field,” which is known to describe the nuclear forces. The nuclear forces, therefore, may be viewed as vibrations of higher dimensional space. Simply put, by adding more dimensions, we are able to describe more forces. Similarly, by adding higher dimensions and further embellishing this approach (with something called “supersymmetry), we can explain the entire particle “zoo” that has been discovered over the past thirty years, with bizarre names like quarks, neutrinos, muons, gluons, etc. Although the mathematics required to extend the idea of Kaluza has reached truly breathtaking heights, startling even professional mathematicians, the basic idea behind unification remains surprisingly simple: the forces of nature can be viewed as vibrations in higher dimensional space.

What Happened Before the Big Bang?

One advantage to having a theory of all forces is that we may be able to resolve some of the thorniest, long-standing questions in physics, such as the origin of the universe, and the existence of “wormholes” and even time machines. The 10 dimensional superstring theory, for example, gives us a compelling explanation of the origin of the Big Bang, the cosmic explosion which took place 15 to 20 billion years ago, which sent the stars and galaxies hurling in all directions. In this theory, the universe originally started as a perfect 10 dimensional universe with nothing in it. In the beginning, the universe was completely empty. However, this 10 dimensional universe was not stable. The original 10 dimensional space-time finally “cracked” into two pieces, a four and a six dimensional universe. The universe made the “quantum leap” to another universe in which six of the 10 dimensions collapsed and curled up into a tiny ball, allowing the remaining four dimensional universe to explode outward at an enormous rate. The four dimensional universe (our world) expanded rapidly, creating the Big Bang, while the six dimensional universe wrapped itself into a tiny ball and shrunk down to infinitesimal size. This explains the origin of the Big Bang. The cur rent expansion of the universe, which we can measure with our instruments, is a rather minor aftershock of a more cataclysmic collapse: the breaking of a 10 dimensional universe into a four and six dimensional universe.

In principle, this also explains why we cannot measure the six dimensional universe, because it has shrunk down to a size much smaller than an atom. Thus, no earth-bound experiment can measure the six dimensional universe because it has curled up into a ball too small to be analyzed by even our most powerful instruments. (This will be disappointing to those who would like to visit these higher dimensions in their lifetimes. These higher dimensions are much too small to enter.)

Time Machines?

Another longstanding puzzle concerns parallel universes and time travel. According to Einstein's theory of gravity, space-time can be visualized as a fabric which is stretched and distorted by the presence of matter and energy. The gravitational field of a black hole, for example, can be visualized as a funnel, with a dead, collapsed star at the very center (see fig. 6). Anyone unfortunate enough to get too close to the funnel inexorably falls into it and is crushed to death. One puzzle, however, is that, according to Einstein's equations, the funnel of a black hole necessarily connects our universe with a parallel universe. Furthermore, if the funnel connects our universe with itself, then we have a "worm hole" (see fig. 7). These anomalies did not bother Einstein because it was thought that travel through the neck of the funnel, called the "Einstein-Rosen bridge," would be impossible (since anyone falling into the black hole would be killed).

However, over the years physicists like Roy Kerr as well as Kip Thorne at the Calif. Institute of Technology have found new solutions of Einstein's equations in which the gravitational field does not become infinite at the center, i.e. in principle, a rocket ship could travel through the Einstein- Rosen bridge to an alternate universe (or a distant part of our own universe) without being ripped apart by intense gravitational fields. (This wormhole is, in fact, the mathematical representation of Alice's Looking Glass.)

Even more intriguing, these wormholes can be viewed as time machines. Since the two ends of the wormhole can connect two time eras, Thorne and his colleagues have calculated the conditions necessary to enter the wormhole in one time era and exit the other side at another time era. (Thorne is undaunted by the fact that the energy necessary to open an Einstein-Rosen bridge exceeds that of a star, and is hence beyond the reach of present-day technology. But to Thorne, this is just a small detail for the engineers of some sufficiently advanced civilization in outer space!) Thorne even gives a crude idea of what a time machine might look like when built. (Imagine, however, the chaos that could erupt if time machines were as common as cars. History books could never be written. Thousands of meddlers would constantly be going back in time to eliminate the ancestors of their enemies, to change the outcome of World War I and II, to save John Kennedy's and Abraham Lincoln's life, etc. "History" as we know it would become impossible, throwing professional historians out of work. With every turn of a time machine's dial, history would be changing like sands being blown by the wind.) Other physicists, however, like Steven Hawking, are dubious about time travel. They argue that quantum effects (such as intense radiation fields at the funnel) may close the Einstein-Rosen bridge. Hawking even advanced an experimental “proof” that time machines are not possible (i.e. if they existed, we would have been visited by tourists from the future).

This controversy has recently generated a flurry of papers in the physics literature. The essential problem is that although Einstein’s equations for gravity allow for time travel, they also break down when approaching the black hole, and quantum effects, such as radiation, take over. But to calculate if these quantum corrections are intense enough to close the Einstein-Rosen bridge, one necessarily needs a unified field theory which includes both Einstein’s theory of gravity as well as the quantum theory of radiation. So there is hope that soon these questions may be answered once and for all by a unified field theory. Both sides of the controversy over time travel acknowledge that ultimately this question will be resolved by the Theory of Everything.

Recreating Creation

Although the 10 dimensional superstring theory has been called the most fascinating discovery in theoretical physics in the past decades, its critics have focused on its weakest point, that it is almost impossible to test. The energy at which the four fundamental forces merge into a single, unified force occurs at the fabulous “Planck energy,” which is a billion billion times greater than the energy found in a proton. Even if all the nations of the earth were to band together and single-mindedly build the biggest atom smasher in all history, it would still not be enough to test the theory. Because of this, some physicists have scoffed at the idea that superstring theory can even be considered a legitimate “theory.” Nobel laureate Sheldon Glashow, for example, has compared the superstring theory to the former Pres. Reagan’s Star Wars program (because it is untestable and drains the best scientific talent).The reason why the theory cannot be tested is rather simple. The Theory of Everything is necessarily a theory of Creation, that is, it must explain everything from the origin of the Big Bang down to the lilies of the field. Its full power is manifested at the instant of the Big Bang, where all its symmetries were intact. To test this theory, therefore, means recreating Creation on the earth, which is impossible with present-day technology. (This criticism applies, in fact, to any theory of Creation. The philosopher David Hume, for example, believed that a scientific theory of Creation was philosophically impossible. This was because the foundation of science depends on reproducibility, and Creation is one event which can never be reproduced in the laboratory.)

Although this is discouraging, a piece of the puzzle may be supplied by the Superconducting Supercollider (SSC), which, if built, will be the world’s largest atom smasher. The SSC (which is likely to be cancelled by Congress) is designed to accelerate protons to a staggering energy of tens of trillions of electron volts. When these sub-atomic particles slam into each other at these fantastic energies within the SSC, temperatures which have not been seen since the instant of Creation will be generated. That is why it is sometimes called a “window on Creation.” Costing /8-10 billion, the SSC consists of a ring of powerful magnets stretched out in a tube over 50 miles long. In fact, one could easily fit the Washington Beltway, which surrounds Washington D.C., inside the SSC. If and when it is built, physicists hope that the SSC will find some exotic sub-atomic particles in order to complete our present-day understanding of the four forces. However, there is also the small chance that physicists might discover “super- symmetric” particles, which may be remnants of the original superstring theory. In other words, although the superstring theory cannot be tested directly by the SSC, one hopes to find resonances from the superstring theory among the debris created by smashing protons together at energies not found since the Big Bang.