Outside The Bounds of Logic

Research in Theoretical Physics

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Preface:

One day, would it be possible to walk through walls? To build ships that can travel faster than the speed of light? To become invisible? To transport our bodies instantly through the outer space?....

I've been wondering about the possibility of time travel, ray guns, force fields, parallel universes…… these things are a playground for imagination and creativity to move the dream into being.

When Albert Einstein died, people were talking about his life and death in hushed tones. The next day newspapers published a picture of his desk with the unfinished manuscript of his greatest unfinished work. The article claimed that Einstein had an impossible dream, a problem so difficult that even Einstein himself couldn't finish it, a manuscript about a grand unifying "theory of everything".

The relativity of the impossible:

In the past some scientists noticed that the borders of south America and Africa fit together, almost like a puzzle game. Scientists said that perhaps they were part of the same vast continent. But that was silly. No force could possibly push two continents away from each other. Such thinking was out of this world, but today we know that through plate tectonics the continents do move. So is it impossible to think we might one day be able to teleport ourselves from one place to another, or build a spaceship that will one day take us light-years away to the stars?

Normally such ideas would be considered impossible by today's physicists. Might they become possible within a few centuries? Or in ten thousand years, when our technology is more advanced? Or in a million years? To put it another way, if we encounter a civilization a million years more advanced than ours, would their everyday technology appear to be "magic" to us? That is one of the central questions running; just because something is "impossible" today, will it remain impossible centuries or millions of years into the future? Given the remarkable advances in science in the past century, especially the creation of the quantum theory and general relativity, it is now possible to give rough estimates of when, if ever, some of these fantastic technologies may be realized. With the coming of even more advanced theories, such as string theory, even concepts bordering on science fiction, such as time travel and parallel universes, are now being re-evaluated by physicists. Think back about 200 years to those technological advances that were declared "impossible" by scientists at the time and that have now become part of our everyday lives. Jules Verne wrote a novel in 1863, *Paris in the twentieth century*, which was locked away and forgotten for over a century until it was accidently discovered by his great-grandson and published for the first time in 1994. In it Verne predicted what Paris might look like in the 1960. His novel was filled with technology that was clearly considered impossible in the nineteenth century, including fax machines, a worldwide communication networks, glass skyscrapers, gas-powered auto mobiles, and high-speed elevated trains.

Sadly, some of the greatest scientists of the nineteenth century took the opposite position and declared any number of technologies to be hopelessly impossible. Lord Kelvin, perhaps the most prominent physicist of the Victorian era declared that "heavier than air" devices such as the airplane was impossible. He thought X-rays were a trick and that radio had no future. Lord Rutherford, who discovered the nucleus of the atom, dismissed the possibility of building an atomic bomb, comparing it to "moonshine". Chemists of the nineteenth century declared the search for the philosopher's stone, a fabled substance that can turn lead into gold, a scientific dead end. Nineteenth-century chemistry was based on the fundamental immutability of the elements, like lead. Yet with today's atom smasher, we can, in principle, turn lead atoms into gold. Think how fantastic today's televisions, computers, and internet would have seemed at the turn of the twentieth century.

More recently, black holes were considered to be science fiction. Einstein himself wrote a paper in 1939 that “proved” that black holes could never form. Yet today the Hubble Space Telescope and Chandra X-ray telescope have revealed thousands of black holes in space, even more scientists think that there is a huge black hole in every single galaxy and that is the reason of why a galaxy still stick together and not fall apart.

The reason that these technologies were deemed “impossibilities” is that the basic laws of physics and science were not known in the nineteenth century and the early part of the twentieth. Given the huge gaps in the understanding of science at the time, especially at the atomic level, it’s no wonder such advances were considered impossible.

The study of impossibilities:

Ironically, the serious study of the impossible has frequently opened up rich and entirely unexpected domains of science. For example, over the centuries the frustrating and futile search for a “perpetual motion machine” led physicists to conclude that such a machine was impossible, forcing them to postulate the conservation of energy and the three laws of thermodynamics. Thus the futile search to build perpetual motion machines helped to open up the entirely new field of thermodynamics, which in part laid the foundation of the steam engine, the machine age, and modern industrial society.

At the end of the nineteenth century, scientists decided that it was “impossible” for the Earth to be billions of years old. Lord Kelvin declared flatly that a molten Earth would cool down in 20 to 40 million years, contradicting the geologists and Darwinian biologists who claimed that the Earth might be billions of years old. The impossible was finally proven to be possible with the discovery of the nuclear force by Madame Curie and others, showing how the center of the Earth, heated by radioactivity, could indeed be kept molten for billions of years.

In the 1920s and 1930s Robert Goddard, the founder of modern rocketry, was the subject of intense criticism by those who thought that rockets could never travel in outer space. They sarcastically called his pursuit Goddard’s Folly. In 1921 the editors of the *New York times* railed against Dr. Goddard’s work: “Professor Goddard does not know the relation between action and reaction and the need to have something better than a vacuum against which to react. He seems to lack the basic knowledge ladled out daily in high schools.” Rockets were impossible, the editor huffed, because there was no air to push against in outer space. Sadly, one head of state did understand the implications of Goddard’s “impossible” rockets- Adolf Hitler. During World War II, Germany’s barrage of impossibly advanced V-2 rockets rained death and destruction on London, almost bringing it to its knees.

Studying the impossible may have also changed the course of world history. In the 1930s it was widely believed, even by Einstein that an atomic bomb was “impossible”. Physicists knew that there was tremendous amount of energy locked deep inside the atom’s nucleus, according to Einstein equation $E = mc^2$, but the energy released by a single nucleus was too insignificant to consider. But atomic physicist Leo Szilard remembered reading the 1914 H. G. Wells novel, *The world set free*, in which Wells predicted the development of the atomic bomb would be solved by a physicist in 1933. By chance Szilard stumbled upon this book in 1932. Spurred by the novel, in 1933, precisely as predicted by Wells some two decades earlier, he hit upon the idea of magnifying the power of a single atom via chain reaction, so that the energy of splitting a single uranium nucleus could be magnified by many trillions. Szilard then set into motion a series of key experiments and secret negotiations between Einstein and President Franklin Roosevelt that would lead to Manhattan project, which built the atomic bomb.

Time and again we see that the study of the impossible has opened up entirely new vistas, pushing the boundaries of physics and chemistry and forcing scientists to redefine what they mean by “impossible”. As Sir William Osler once said,” The philosophies of one age have become the absurdities of the next, and the foolishness of yesterday has become the wisdom of tomorrow.”

Many physicists subscribe to the famous dictum of T.H>White, who wrote in *The Once and Future King*, “Anything that is not forbidden, is mandatory!” In physics we find evidence of this all the time. Unless there is a law of physics explicitly preventing a new phenomenon, we eventually find that it exists. (This has happened several times in the search for new subatomic particles, by probing the limits of what is forbidden, physicists have often unexpectedly discovered new laws of physics.) A corollary to T. H. White’s statement might well be, “Anything that is not impossible, is mandatory!”

For example, cosmologist Stephen Hawking tried to prove that time travel was impossible by finding a new law of physics that would forbid it, which he called "chronology protection conjecture." Unfortunately, after many years of hard work he was unable to prove this principle. In fact, to the contrary, physicists have now demonstrated that a law that prevents time travel is beyond our present-day mathematics. Today, because there is no law of physics preventing the existence of time machines, physicists have had to take their possibility very seriously.

The purpose of this research is to consider what technologies are considered “impossible” today that might well become commonplace decades to centuries down the road.

Already one “impossible” technology is now proving to be possible: the notion of teleportation (at least at the level of atoms). Even a few years ago physicists would have said that sending or beaming an object from one point to another violated the laws of quantum physics. The writers of the original *Star Trek* television series, in fact, were so stung by the criticism from physicists that they added “Heisenberg compensators” to explain their teleporters in order to address this flaw. Today, because of a recent breakthrough, physicists can teleport atoms across a room or photons under the Danube River.

Predicting The Future:

It is always a bit dangerous to make predictions, especially ones set centuries to thousands of years in the future. The physicist Niels Bohr was fond of saying,” Prediction is very hard to do. Especially about the future.” But there is a fundamental difference between the time of Jules Verne and the present. Today the fundamental laws of physics are basically understood. Physicists today understand the basic laws extending over a staggering forty-three orders of magnitude, from the interior of the proton out to the expanding universe. As a result, physicists can state, with reasonable confidence, what the broad outlines of future technology might look like, and better differentiate between those technologies that are merely improbable and those that are truly impossible.

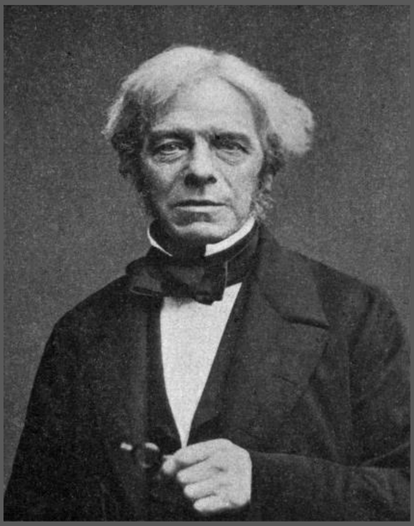
In this research, therefore, I divide the things that are “impossible” into three categories

The first are *Class I impossibilities*. These are technologies that are impossible today but do not violate the known laws of physics. So they might be possible in this century, or perhaps the next, in modified form. They include teleportation, antimatter engines, and invisibility.

The second category are *Class II impossibilities*. These are technologies that sit at very edge of our understanding of the physical world. If they are possible at all, they might be realized on a scale of millennia to millions of years in the future. They include time machines, the possibility of hyperspace travel, and travel through wormholes.

The final category are *Class III impossibilities.* These are technologies that violate the known laws of physics. Surprisingly, there are very few such impossible technologies. If they do turn out to be possible, they would represent a fundamental shift in our understanding of physics.

Michael Faraday



Faraday was born to working-class parents and eked out a meager existence as an apprentice bookbinder in the early 1800s. The young Faraday was fascinated by the enormous breakthroughs in uncovering the mysterious properties of two new forces: electricity and magnetism. Faraday devoured all he could concerning these topics and attended lectures by Professor Humphrey Davy of the Royal Institution in London. One-day Professor Davy severely damaged his eyes in a chemical accident and hired Faraday to be his secretary. Faraday slowly began to win the confidence of the scientists at the Royal Institution and was allowed to conduct important experiments of his own, although he was often slighted. Over the years Professor Davy grew increasingly jealous of the brilliance shown by his young assistant, who was a rising star in experimental circles, eventually eclipsing Davy's own fame. After Davy died in 1829 Faraday was free to make a series of stunning breakthroughs that led to the creation of generators that would energize entire cities and change the course of world civilization. (Because of Faraday's poverty stricken youth, he was illiterate in mathematics, and as a consequence his notebooks are full not of equations but of hand-drawn diagrams of these lines of force. Ironically, his lack of mathematical training led him to create the beautiful diagrams of lines of force that now can be found in any physics textbook. In science a physical picture is often more important than the mathematics used to describe it.)

Carl Sagan once wrote,” what does it mean for a civilization to be a million years old? We have had radio telescopes and spaceships for a few decades; our technical civilization is a few hundred years old. . . an advanced civilization millions of years old is much beyond us as we are beyond a bush baby or a macaque.”

So……..

What kinds of energy will we have after a few decades?

How technology will become?

Class I impossibilities

1: Force Fields

What is a force field? In science fiction, it’s very simple: a thin, invisible yet impenetrable barrier that can deflect lasers and rockets or whatever hits it.

Like Edison’s lightbulb revolutionized modern civilization, a force field could affect every aspect of our lives. The military could use force fields to become invulnerable, creating an undefeatable shield against enemy missiles and bullets. Bridges, superhighways, and roads could in theory be built by simply pressing a button. Entire cities could sprout instantly in the desert, with skyscrapers made entirely of force fields. Force fields erected over cities could enable their inhabitants to modify the effects of their weather-high winds, blizzards, tornados-at will. Cities could be built under the oceans within the safe canopy of a force field. Glass, steel, and mortar could be entirely replaced.

Yet oddly enough a force field is perhaps one of the most difficult devices to create in the lab. In fact, some physicists believe it might actually be impossible, without modifying its properties.

Michael Faraday:

The key to Faraday’s greatest discoveries was his “force fields.” If one places iron filings over a magnet, one finds that the iron filings create a specific pattern that fills up all of space. These are Faraday’s lines of force, which graphically describe how the force fields of electricity and magnetism fill space. If one graphs the magnetic fields of the earth, for example, one finds that the lines emanate from north polar region and then fall back to the Earth in the south polar region. Empty space, to Faraday, wasn’t empty at all, but was filled with lines of force concentrate at the tip of the lightning rod in a thunderstorm, one would find that the lines of force that could make distant objects move. Historians have speculated on how Faraday was led to his discovery of force fields, one of the most important concepts in all of science. In fact, the sum total of all modern physics is written in the language of Faraday’s fields. In 1831, he made the key breakthrough regarding force fields that changed civilization forever. One day, he was moving a child’s magnet over a coil of wire, without ever touching it. This meant that a magnet’s invisible field could push electrons in a wire across empty space, creating a current. Faraday’s “force fields,” which were previously thought to be useless, idle doodling, were real, material forces that could move objects and generate power. Today the light that we use is probably energized by Faraday’s discovery about electromagnetism. A spinning magnet creates a force field that pushes the electrons in a wire, causing them to move in an electrical current. This electricity in the wire can then be used to light up a lightbulb. This same principle is used to generate electricity to power the cities of the world. Water flowing across a dam, for example, causes a huge magnet in turbine to spin, which then pushes the electrons in a wire, forming an electric current that is sent across high-voltage wires into our homes.

The Basic Forces:

Over the last two thousand years one of the crowning achievements of physics has been the isolation and identification of the basic forces that controls our universe. All of them can be described in the language of fields introduced by Faraday [1]. Unfortunately, however, none of them has quite the properties of the force fields described in most science fiction. These forces are:

I – Gravity, the force that keeps our bodies on the ground, prevents the Earth and the stars from colliding, and holds the solar system and galaxy together. Without gravity, we would be lance off the Earth into space at the rate of 1,000 miles per hour by the spinning planet. The problem is that gravity has precisely the opposite properties of a force field found in science fiction. Gravity is attractive, not repulsive, it’s extremely weak, relatively speaking and works over enormous, astronomical distances. In other words, it is almost the opposite of the flat, thin, impenetrable barrier that we read about in science fiction novels or movies. For example, it takes the entire Earth to attract a feather to the floor, but we can counteract Earth’s gravity by lifting the feather with a finger. The action of our finger can counteract the gravity of an entire planet that weighs over six trillion trillion kilograms.

II – Electromagnetism (EM), the force that lights up our cities. Lasers, radio, TV, modern electronics, computers, the Internet, electricity, magnetism- all are results of the electromagnetism force. It is perhaps the most useful force ever geared by humans. Unlike gravity, it can be both attractive and repulsive. However, there are several reasons that it is unsuitable as a force field. First, it can be easily neutralized/ plastics and other insulators, for example, can easily penetrate a powerful electric or magnetic field. A piece of plastic thrown in a magnetic field would pass right through. Second, electromagnetism acts over large distances and cannot easily be focused onto a plane. The laws of the EM force are described by James Clerk Maxwell’s equations, and these equations do not seem to admit force fields as solutions.

III & IV – The nuclear forces. The weak force is the force of radioactive decay. It is the force that heats up the center of the Earth, which is radioactive. It is the force behind volcanoes, earthquakes, and continental drift. The strong force holds the nucleus of the atom together. [2]The energy of the sun and stars originates from the nuclear force, which is responsible for lighting up the universe. The problem is that the nuclear force is a short range force, acting mainly over the distance of a nucleus. Because it

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[1] Fundamental forces of nature,2007, Huang, Kerson

[2] Fundamental forces of nature,2007, Huang, Kerson

is so bound to the properties of nuclei, it is extremely hard to manipulate. At present the only ways we have of manipulating this force are to blow subatomic particles apart in atom smashers or to detonate atomic bombs.

Although the force fields used in science fiction may not conform to the known laws of physics, there are still chances that might make the creation of such a force field possible. First, there may be a fifth force, still unseen in the laboratory. Such a force might, for example, work over a distance of only a few inches to feet, rather than over astronomical distances.

Second, it may be possible to use a plasma to copy some of the properties of a force field. A plasma is the "fourth state of matter." Solids, liquids, and gases make up the three familiar states of matter, but the most common form of matter in the universe is plasma, a gas of ionized atoms. Because the atoms of plasma are ripped a part, with electrons turn off the atom, the atoms are electrically charged and can be easily manipulated by electric and magnetic fields.

Plasmas are the most plentiful form of visible matter in the universe, making up the sun, the stars, and interstellar gas. Plasmas are not familiar to us because they are only rarely found on the earth, but we can see them in the form of lightning bolts, the sun, and the interior of our plasma TV.

For me I don't see it like this, I think that the four forces are related but we didn't discover the equations that relates them to each other, because philosophically speaking something can't have more than one essence. let's talk about gravity and electromagnetism are related.

Any moving mass creates a distortion in space-time but what about unmoving mass?? It has an effect on any other object that means that even us with all this tiny mass can affect the whole galaxies in the universe. But our gravitational force is too small to do it that's why I'm convinced that gravity has to be a form of electromagnetism or vice versa.

Plasma windows:

If a gas is heated to a high enough temperature, it becomes a plasma, it can be molded and shaped by magnetic and electrical fields. It can, for example, be shaped in the form of a sheet or window. Moreover, this "plasma windows" can be used to separate a vacuum from ordinary air. In principle, one might be able to prevent the air within a spaceship from leaking out into space, thereby creating a convenient, transparent interface between outer space and the spaceship.

The plasma window was invented by physicist Ady Herschcovitch in 1995 at the Brookhaven National Laboratory in Long Island, New York, United States of America. [3]He developed it to solve the problem of how to weld metals using electron beams. A welder's acetylene torch uses a blast of hot gas to melt and then weld metal pieces together. But a beam of electrons can weld metals faster, cleaner, and more cheaply than ordinary methods. The problem with electron beam welding, however, is that it needs to be done in a vacuum. This requirement is quite inconvenient, because it means creating a vacuum box that may be as big as an entire room.

Dr. Herschcovitch invented the plasma window to solve this problem. Only 3 feet high and less than 1 foot in diameter, the plasma window heats gas to 12,000° F, creating a plasma that is trapped by electric and magnetic fields. These particles exert pressure, as in any gas, which prevents air from rushing into the vacuum chamber, thus separating air from the vacuum.[4]

The plasma window has wide applications for space travel and industry. Many times, manufacturing process need a vacuum to perform microfabrication and dry etching for industrial purposes, but working

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[3] Fusion Plasma Diagnostics with Mm-Waves: An Introduction,2013, Hartfuß, Hans-Jürgen Geist, Thomas.

[4] Systems and methods for plasma propulsion,2009,Allen.E.H.

in a vacuum can be expensive. But with the plasma window one can cheaply contain a vacuum with just pressing a button.

But can the plasma window also be used as an impenetrable shield? Can it withstand a blast from a cannon? In the future, one can imagine a plasma window of much greater power and temperature, sufficient to damage or vaporize incoming projectiles. But to create a more realistic force field, like that found in science fiction, one would need a combination might suffice.

The outer layer could be a supercharged plasma window, heated to temperature high enough to vaporize metals. A second layer could be made of high-energy laser beams. This layer, containing thousands of crisscrossing laser beams, would create a lattice that would heat up objects that passed through it, effectively vaporizing them.

And behind this laser layer one might envision a lattice made of “carbon nanotubes,” tiny tubes made of individual carbon atoms that are one atom thick and that are many times stronger than steel.

Although the current world record for a carbon nanotube is only about 15 millimeters long, one can envision a day when we might be able to create carbon nanotubes of meters’ length. Assuming that carbon nanotubes can be woven into a lattice, they could create a screen of enormous strength, capable of repelling most objects. The screen would be invisible, since each carbon nanotube lattice would be stronger than any ordinary material.

So, via a combination of plasma window, laser layer, and carbon nanotube screen, one might imagine creating an invisible wall that would be nearly impenetrable by most means.

Yet even this multilayered shield would not completely fulfill all the properties of a science fiction force field- because it would be transparent and therefore incapable of stopping a laser beam. In a battle with laser cannons, the multilayered shield would be useless.

To stop a laser beam, the shield would also need to possess an advanced form of “photo chromatics.” This is the process used in sunglasses that darken by themselves upon exposure to UV radiation. Photo chromatics are based on molecules that can exist in at least two states. In one state the molecule is transparent. But when it is exposed to UV radiation it instantly changes to second form, which is opaque.

One day we might be able to use nanotechnology to produce a substance as tough as carbon nanotubes that can change its optical properties when exposed to laser light. In this way, a shield might be able to stop a laser blast as well as a particle beam or cannon fire. At present, however, photo chromatics that can stop laser beams do not exist.

MAGLEV TRAINS

Maglev (derived from ***mag***netic ***lev***itation) is a transport method that uses magnetic levitation to move vehicles without touching the ground. With maglev, a vehicle travels along a guideway using magnets to create both lift and propulsion, thereby reducing friction by a great extent and allowing very high speeds.

Magnetic levitation:

In science fiction, force fields have another purpose besides deflecting ray-gun blasts, and that is to serve as a platform to defy gravity. In science fiction movies, actors ride a “hover board,” which resembles a skateboard except that it floats over the street. Such as antigravity device is impossible given the laws of physics as we know them today. But magnetically enhanced hover boards and hover cars could become a reality in the future, giving us the ability to levitate large objects at will. In the future, if “room temperature superconductors” become a reality, one might be able to levitate objects using the power of magnetic force fields.

If we place two bar magnets next to each other with north poles opposite each other, the two magnets repel each other. This same principle, that north poles repel each other, can be used to lift enormous weight off the ground. Already several nations are building advanced magnetic levitation trains that hover just above the railroad tracks using ordinary magnets. Because they have zero friction, they can attain record-breaking speeds, floating over a cushion of air.

In 1984 the world’s first commercial automated maglev system began operation in the United Kingdom, running from Birmingham International Airport to the nearby Birmingham International railway station.[5] Maglev trains have also been built in Germany, Japan, and Korea, although most of them have not been designed for high velocities. The first commercial maglev train operating at high velocities is the initial operating segment (IOS) demonstration line in Shanghai, which travels at a top speed of 268 miles per hour. The Japanese maglev train in Yamanashi prefecture attained a velocity of 361 miles per hour, even faster than the usual wheeled trains.

But these maglev devices are extremely expensive. One way to increase efficiency would be to use superconductors, which lose all electrical resistance when they are cooled down to near absolute zero. Superconductivity was discovered in 1911 by Heike Onnes. If certain substances are cooled to below 20 K above absolute zero, all electrical resistance is lost. Usually when we cool down the temperature of a metal, its resistance decreases gradually. (This is because random vibrations of the atom impede the flow of electrons in a wire. By reducing the temperature, these random motions are reduced, and hence electricity flows with less resistance.) But much Onne’s surprise, he found that resistance of certain materials fell abruptly to zero at a critical temperature.

Physicists immediately recognized the importance of this result.

Power lines lose a significant amount of energy by transporting electricity across long distances. But if all resistance could be eliminated, electrical power could be transmitted almost for free. In fact, if electricity were made to circulate in a coil of wire, the electricity would circulate for millions of years, without any lost in energy. Furthermore, magnets of incredible power could be made with little effort from these enormous electric currents. With these magnets, one could lift huge loads with ease.

Despite all these miraculous powers, the problem with superconductivity is that it is very expensive to immerse large magnets in vats of super cooled liquid. Huge refrigeration magnets prohibitively expensive.

But one day physicists may be able to create a “room-temperature superconductor,” the holy grail of solid-state physicists. The invention of room-temperature superconductors in the laboratory would spark a second industrial revolution. Powerful magnetic fields capable of lifting cars and trains would become so cheap that hover cars might become economically feasible. With room-temperature superconductors,

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[5] Rising Forces,2011, Livingston, James

High-temperature superconductors

high-temperature superconductors are made of atoms arranged in distinctive layers.
Many physicists theorize that this layering of the ceramic material
makes it possible for electrons to flow freely within each layer, creating
a superconductor. But precisely how this is done is still a mystery.

the fantastic flying cars seen in *Back to the Future*, *Minority Report*, and *Star Wars* might become a reality.

In principle, one might be able to wear a belt made of superconducting magnets that would enable one of effortlessly levitate off the ground. With such a belt, one could fly in the air like superman.

Room-temperature superconductors are so remarkable that they appear in numerous science fiction novels.

For decades, physicists have searched for room-temperature superconductors without success. It has been a tedious, hit or miss process, testing one material after another. But in 1986 a new class of substances called" high temperature superconductors" was found that became superconductors at about 90 degrees above absolute zero, or 90K, creating a sensation in the world of physics. The floodgates seemed to open. Month after month, physicists raced one another to break the next world's record for a superconductor. For a brief moment it seemed as if the possibility of room-temperature superconductors would leap off the pages of science fiction novels and into our living rooms. But after a few years of moving at breakneck speed, research in high-temperature superconductors began to slow down.

At present the world's record for a high-temperature superconductor is held by a substance called mercury thallium barium calcium copper oxide, which becomes superconducting at 138 K (-133 C). this relatively high temperature is still a long way from room temperature. But this 138K record is still important. Nitrogen liquefies at 77 K, and liquid nitrogen costs about as much as ordinary milk. Hence ordinary liquid nitrogen could be used to cool down these high-temperature superconductors rather cheaply.

Embarrassingly enough, at present there is no theory explaining the properties of these high-temperature superconductors. In fact, a noble prize is awaiting the enterprising physicist who can explain how high-temperature superconductors work.

Because of this lack of knowledge, physicists unfortunately resort to a hit-or-miss procedure to search for new high-temperature superconductors. This means that the fabled room-temperature superconductor may be discovered tomorrow, next year, or not at all. No one knows when, or if such a substance will ever be found.

But if room-temperature superconductors are discovered, a tidal wave of commercial applications could be set off. Magnetic fields that are a million times more powerful than the Earth's magnetic field might become commonplace.

One common property of superconductivity is called the Meissner effect. If you place a magnet above a superconductor, the magnet will levitate, as if held upward by some invisible force.

Using the Meissner effect, one can imagine a future in which the highways are made of these special ceramics. Then magnets placed in our belts or our tires could enable us to magically float to our destination, without any friction or energy loss.

Meissner Effect

The reason for the Meissner effect is that the magnet has the effect of creating a "mirror image" magnet within the superconductor, so that the original magnet and the mirror-image magnet repel each other. Another way to see this is that magnetic fields cannot penetrate into a superconductor. Instead, magnetic fields are expelled. So if a magnet is held above a superconductor, its lines of force are expelled by the superconductor, and the lines of force then push the magnet upward, causing it to levitate.

The Meissner effect works only on magnetic materials, such as metals. But it is also possible to use superconducting magnets to levitate nonmagnetic materials, called paramagnets and diamagnets. These substances do not have magnetic properties of their own; they acquire their magnetic properties only in the presence of an external magnetic field. Paramagnets are attracted by an external magnet, while diamagnets are repelled by an external magnet.

Water, for example, is a diamagnet. Since all living things are made of water, they can levitate in the presence of a powerful magnetic field. In a magnetic field about 15 teslas (30,000 times the Earth’s field), scientists have levitated small animals, such as frogs. But if room-temperature superconductors become a reality, it should be possible to levitate large nonmagnetic objects as well, via there diamagnetic property.

In conclusion, force fields as commonly described in science fiction do not fit the description of the four forces of the universe. Yet it may be possible to simulate many of the properties of force fields by using a multilayered shield, consisting of plasma windows, laser curtains, carbon nanotubes, and photo chromatics. But developing such a shield could be many decades, or even a century, away. And if room-temperature superconductors can be found, one might be able to use powerful magnetic fields to levitate cars and trains and soar in the air, as in science fiction movies.

Given these considerations, I would classify force fields as a Class I impossibility-that is, something that is impossible by today’s technology, but possible, in modified form, within a century or so.

2: Teleportation

Teleportation, or the ability to transport a person or object instantly from one place to another, is a technology that could change the course of civilization and alter the destiny of nations. It could irrevocably alter the rules of warfare: armies could teleport troops behind enemy lines or simply teleport the enemy's leadership and capture them. Today's transportation system-from cars and ships to airplanes and railroads, and all the many industries that service these systems would become obsolete; we could simply teleport ourselves to work and our goods to market. Vacations would become effortless, as we teleport ourselves to our destination. Teleportation would change everything.
The earliest mention of teleportation can be found in religious texts such as the Bible, where spirits whisk individuals away.[6] This passage from Acts in the New Testament seems to suggest the teleportation of Philip from Gaza to Azotus: "When they came up out of the water, the Spirit of the

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[6] Dance of the photons: From Einstein to quantum teleportation,2010, Zeilinger, Anton.

Lord suddenly took Philip away, and the eunuch did not see him again, but went on his way rejoicing. Philip, however, appeared at Azotus and traveled about, preaching the gospel in all the towns until he reached Caesarea"

Teleportation is also part of every magician's bag of tricks and illusions: pulling rabbits out of a hat, cards out of his or her sleeves, and coins from behind someone's ear. One of the more ambitious magic tricks of recent times featured an elephant disappearing before the eyes of a startled audience. In this demonstration a huge elephant, weighing many tons, was placed inside a cage. Then, with a flick of a magician's wand, the elephant vanished, much to the amazement of the audience. (Of course, the elephant really did not disappear. The trick was performed with mirrors. Long, thin, vertical mirror strips were placed behind each bar of the cage. Like a gate, each of these vertical mirror strips could be made to swivel. At the start of the magic trick, when all these vertical mirror strips were aligned behind the bars, the mirrors could not be seen and the elephant was visible. But when the mirrors were rotated by 45 degrees to face the audience, the elephant disappeared, and the audience was left staring at the reflected image from the side of the cage.)

Teleportation And Science Fiction

The earliest mention of teleportation in science fiction occurred in Edward Page Mitchell's story "The Man Without a Body," published in 1877. In that story a scientist was able to disassemble the atoms of a cat and transmit them over a telegraph wire. Unfortunately the battery died while the scientist was trying to teleport himself. Only his head was successfully teleported.

Sir Arthur Conan Doyle, best known for his Sherlock Holmes novels, was fascinated by the notion of teleportation. After years of writing detective novels and short stories he began to tire of the Sherlock Holmes series and eventually killed off his sleuth, having him plunge to his death with Professor Moriarty over a waterfall. But the public outcry was so great that Doyle was forced to resurrect the detective.

Because he couldn't kill off Sherlock Holmes, Doyle instead decided to create an entirely new series, featuring Professor Challenger, who was the counterpart of Sherlock Holmes. Both had a quick wit and a sharp eye for solving mysteries. But while Mr. Holmes used cold, deductive logic to break open complex cases, Professor Challenger explored the dark world of spirituality and paranormal phenomena, including teleportation.

In the 1927 novel *The Disintegration Machine,* the professor encountered a gentleman who had invented a machine that could disintegrate a person and then reassemble him somewhere else. But Professor Challenger is horrified when the inventor boasts that his invention could, in the wrong hands, disintegrate entire cities with millions of people with a push of a button. Professor Challenger then uses the machine to disintegrate the inventor, and leaves the laboratory, without reassembling him.

More recently Hollywood has discovered teleportation. The 1958 film *The Fly* graphically examined what could happen when teleportation goes horribly awry. When a scientist successfully teleports himself across a room, his atoms mix with those of a fly that accidentally entered the teleportation chamber, so the scientist turns into a grotesquely mutated monster, half human and half fly.

Teleportation first became prominent in popular culture with the *Star Trek* series. Gene Roddenberry, *Star Treks* creator, introduced teleportation into the series because the Paramount Studio budget did not allow for the costly special effects needed to simulate rocket ships taking off and landing on distant planets. It was cheaper simply to beam the crew of the *Enterprise* to their destination.

Over the years any number of objections have been raised by scientists about the possibility of teleportation. To teleport someone, you would have to know the precise location of every atom in a living body, which would probably violate the Heisenberg uncertainty principle (which states that you cannot know both the precise location and the velocity of an electron). The producers of the *Star Trek* series, bowing to the critics, introduced "Heisenberg Compensators" in the transporter room, as if one could compensate for the laws of quantum physics by adding a gadget to the transporter. But as it turns out, the need to create these Heisenberg Compensators might have been premature. Early critics and scientists may have been wrong.

Teleportation and The Quantum Theory

According to Newtonian theory, teleportation is clearly impossible. Newton's laws are based on the idea that matter is made of tiny, hard billiard balls. Objects do not move until they are pushed; objects do not suddenly disappear and reappear somewhere else.

But in the quantum theory, that's precisely what particles can do. Newton's laws, which held sway for 250 years, were overthrown in 1925 when Werner Heisenberg, Erwin Schrödinger, and their colleagues developed the quantum theory. When analyzing the bizarre properties of atoms, physicists discovered that electrons acted like waves and could make quantum leaps in their seemingly chaotic motions within the atom.

The man most closely associated with these quantum waves is the Viennese physicist Erwin Schrödinger, who wrote down the celebrated wave equation that bears his name, one of the most important in all of physics and chemistry. Entire courses in graduate school are devoted to solving his famous equation, and entire walls of physics libraries are full of books that examine its profound consequences. In principle, the sum total of all of chemistry can be reduced to solutions to this equation.

In 1905 Einstein had shown that waves of light can have particle like properties; that is, they can be described as packets of energy called photons. But by the 1920s it was becoming apparent to Schrödinger that the opposite was also true: that particles like electrons could exhibit wavelike behavior. This idea was first pointed out by French physicist Louis de Broglie, who won the Nobel Prize for this conjecture.

One day Schrödinger gave a lecture on this curious phenomenon. He was challenged by a fellow physicist, Peter Debye, who asked him:

If electrons are described by waves, then what is their wave equation?

Ever since Newton created the calculus, physicists had been able to describe waves in terms of differential equations, so Schrödinger took Debye's question as a challenge to write down the differential equation for electron waves. That month Schrödinger went on vacation, and when he came back he had that equation. So in the same way that Maxwell before him had taken the force fields of Faraday and extracted Maxwell's equations for light, Schrödinger took the matter-waves of de Broglie and extracted Schrodinger's equations for electrons.

When Schrödinger began to solve his equation for the hydrogen atom, he found, much to his surprise, the precise energy levels of hydrogen that had been carefully catalogued by previous physicists. He then realized that the old picture of the atom by Niels Bohr showing electrons whizzing around the nucleus (which is used even today in books and advertisements when trying to symbolize modern science)

was actually wrong. These orbits would have to be replaced by waves surrounding the nucleus.

Schrodinger's work sent shock waves, as well, through the physics community. Suddenly physicists were able to peer inside the atom itself, to examine in detail the waves that made up its electron shells, and to extract precise predictions for these energy levels that fit the data perfectly.

But there was still a nagging question that haunts physics even today. If the electron is described by a wave, then what is waving? This has been answered by physicist Max Born, who said that these waves are actually waves of probability. These waves tell you only the chance of finding a particular electron at any place and any time. In other words, *the electron is a particle, but the probability of finding that particle is given by Schrodinger's wave.* The larger the wave, the greater the chance of finding the particle at that point.

With these developments, suddenly chance and probability were being introduced right into the heart of physics, which previously had given us precise predictions and detailed trajectories of particles, from planets to comets to cannon balls.[7]

This uncertainty was finally codified by Heisenberg when he proposed the uncertainty principle, that is, the concept that you cannot know both the exact velocity and the position of an electron at the same

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[7] Dance of the photons: From Einstein to quantum teleportation,2010, Zeilinger, Anton

time. Nor can you know its exact energy, measured over a given amount of time. At the quantum level all the basic laws of common sense are violated: electrons can disappear and reappear elsewhere, and electrons can be many places at the same time.

(Ironically, Einstein, the father of the quantum theory who helped to start the revolution in 1905, and Schrödinger, who gave us the wave equation, were horrified by the introduction of chance into fundamental physics. Einstein wrote, "Quantum mechanics calls for a great deal of respect. But some inner voice tells me that this is not the true Jacob. The theory offers a lot, but it hardly brings us any closer to the Old Man's secret. For my part, at least, I am convinced that He doesn't throw dice.")

Heisenberg's theory was revolutionary and controversial-but it worked. In one sweep, physicists could explain a vast number of puzzling phenomena, including the laws of chemistry. Such a teleportation event is impossible under Newtonian physics but is actually allowed under quantum mechanics. The answer, however, is that one would have to wait longer than the lifetime of the universe for this to occur. (If you used a computer to graph the Schrödinger wave of your own body, you would find that it very much resembles all the features of your body, except that the graph would be a bit fuzzy, with some of your waves oozing out in all directions. Some of your waves would extend even as far as the distant stars. So there is a very tiny probability that one day you might wake up on a distant planet.)

The fact that electrons can seemingly be many places at the same time forms the very basis of chemistry. We know that electrons circle around the nucleus of an atom, like a miniature solar system. But atoms and solar systems are quite different; if two solar systems collide in outer space, the solar systems break apart and planets are flung into deep space. Yet when atoms collide they often form molecules that are perfectly stable, sharing electrons between them.

In other words, all of chemistry, which explains the molecules inside our bodies, is based on the idea that electrons can be many places at the same time, and it is this sharing of electrons between two atoms that holds the molecules of our body together. *Without the quantum theory, our molecules and atoms would dissolve instantly.*

This peculiar but profound property of the quantum theory (that there is a finite probability that even the most bizarre events may happen) was exploited by Douglas Adams in his hilarious novel *The Hitchhiker's Guide to the Galaxy.* He needed a convenient way to whiz through the galaxy, so he invented the Infinite Improbability Drive, "a wonderful new method of crossing vast interstellar distances in a mere nothingth of a second, without all that tedious mucking around in hyperspace." His machine enables you to change the odds of any quantum event at will, so that even highly improbable events become commonplace. So if you want to jet off to the nearest star system, you would simply change the probability that you will rematerialize on that star, and voilà! You would be instantly teleported there. In reality the quantum "jumps" so common inside the atom cannot be easily generalized to large objects such as people, which contain trillions upon trillions of atoms. Even if the electrons in our body are dancing and jumping in their fantastic journey around the nucleus, there are so many of them that their motions average out. That is, roughly speaking, why at our level substances seem solid and permanent.

So while teleportation is allowed at the atomic level, one would have to wait longer than the lifetime of the universe to actually witness these bizarre effects on a macroscopic scale. But can one use the laws of the quantum theory to create a machine to teleport something on demand, as in science fiction stories? Surprisingly, the answer is a qualified yes.

The EBR Experiment[8]

The key to quantum teleportation lies in a celebrated 1935 paper by Albert Einstein and his colleagues Boris Podolsky and Nathan Rosen, who, ironically, proposed the EPR experiment (named for the three authors) to kill off, once and for all, the introduction of probability into physics. (Bemoaning the undeniable experimental successes of the quantum theory, Einstein wrote, "the more success the quantum theory has, the sillier it looks")

If two electrons are initially vibrating in unison (a state called coherence) they can remain in wavelike synchronization even if they are separated by a large distance. Although the two electrons may be separated by light-years, there is still an invisible Schrödinger wave connecting both of them, like an

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[8] Quantitative Epr,2010, Eaton, Gareth R Eaton, Sandra S Barr, David P Weber, Ralph T

umbilical cord. If something happens to one electron, then some of that information is immediately transmitted to the other. This is called "quantum entanglement," the concept that particles vibrating in coherence have some kind of deep connection linking them together.

Let's start with two coherent electrons oscillating in unison. Next, let them go flying out in opposite directions. Each electron is like a spinning top. The spins of each electron can be pointed up or down. Let's say that the total spin of the system is zero, so that if the spin of one electron is up, then you know automatically that the spin of the other electron is down. According to the quantum theory, before you make a measurement, the electron is spinning neither up nor down but exists in a nether state where it is spinning both up and down simultaneously. (Once you make an observation, the wave function "collapses," leaving a particle in a definite state.)

Next, measure the spin of one electron. It is, say, spinning up. Then you know instantly that the spin of the other electron is down. Even if the electrons are separated by many light-years, you instantly know the spin of the second electron as soon as you measure the spin of the first electron. In fact, *you know this faster than the speed of light!* Because these two electrons are "entangled," that is, their wave functions beat in unison, their wave functions are connected by an invisible "thread" or umbilical cord. Whatever happens to one automatically has an effect on the other. (This means, in some sense, that what happens to us automatically affects things instantaneously in distant corners of the universe, since our wave functions were probably entangled at the beginning of time. In some sense there is a web of entanglement that connects distant corners of the universe, including us.) Einstein derisively called this "spooky-action-at-distance," and this phenomenon enabled him to "prove" that the quantum theory was wrong, in his mind, since nothing can travel faster than the speed of light.

Originally, Einstein designed the EPR experiment to serve as the death knell of the quantum theory. But in the 1980s Alan Aspect and his colleagues in France performed this experiment with two detectors separated by 13 meters, measuring the spins of photons emitted from calcium atoms, and the results agreed precisely with the quantum theory.

Did information really travel faster than light? Was Einstein wrong about the speed of light being the speed limit of the universe? Not really. Information did travel faster than the speed of light, but the information was random, and hence useless. You cannot send a real message, or Morse code, via the EPR experiment even if information is traveling faster than light.

Knowing that an electron on the other side of the universe is spinning down is useless information. You cannot send today's stock quotations via this method. For example, let's say that a friend always wears one red and one green sock, in random order. Let's say you examine one leg, and the leg has a red sock on it. Then you know, faster than the speed of light, that the other sock is green. Information actually traveled faster than light, but this information is useless. No signal containing nonrandom information can be sent via this method.

For years the EPR experiment was used as an example of the resounding victory of the quantum theory over its critics, but it was a hollow victory with no practical consequences. Until now.

Quantum Teleportation

Everything changed in 1993, when scientists at IBM, led by Charles Bennett, showed that it was physically possible to teleport objects, at least at the atomic level, using the EPR experiment.[9] (More precisely, they showed that you could teleport all the information contained within a particle.) Since then physicists have been able to teleport photons and even entire cesium atoms. Within a few decades, scientists may be able to teleport the first DNA molecule and virus.

Quantum teleportation exploits some of the more bizarre properties of the EPR experiment. In these teleportation experiments physicists start with two atoms, A and C. Let's say we wish to teleport information from atom A to atom C. We begin by introducing a third atom, B, which starts out being entangled with C, so B and C are coherent. Now atom A comes in contact with atom B. A scans B, so that the information content of atom A is transferred to atom B. A and B become entangled in the process. But since B and C were originally entangled, the information within A has now been transferred to atom C.

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[9] Dance of the photons: From Einstein to quantum teleportation,2010, Zeilinger, Anton

In conclusion, atom A has now been teleported into atom C, that is, the information content of A is now identical to that of C.

Notice that the information within atom A has been destroyed (so we don't have two copies after the teleportation). This means that anyone being hypothetically teleported would die in the process. But the information content of his body would appear elsewhere. Notice also that atom A did not move to the position of atom C. On the contrary, it is the information within A (e.g., its spin and polarization) that has been transferred to C. (This does not mean that atom A was dissolved and then zapped to another location. It means that the information content of atom A has been transferred to another atom, C.)

Since the original announcement of this breakthrough, progress has been fiercely competitive as different groups have attempted to outrace each other. The first historic demonstration of quantum teleportation in which photons of ultraviolet light were teleported occurred in 1997 at the University of Innsbruck. This was followed the next year by experimenters at Cal Tech who did an even more precise experiment involving teleporting photons.

In 2004 physicists at the University of Vienna were able to teleport particles of light over a distance of 600 meters beneath the River Danube, using a fiber-optic cable, setting a new record.

One criticism of these experiments is that they were conducted with photons of light. This is hardly the stuff of science fiction. It was significant, therefore, in 2004, when quantum teleportation was demonstrated not with photons of light, but with actual atoms, bringing us a step closer to a more realistic teleportation device. The physicists at the National Institute of Standards and Technology in Washington, D.C., successfully entangled three beryllium atoms and transferred the properties of one atom into another. This achievement was so significant that it made the cover of *Nature* magazine. Another group was able to teleport calcium atoms as well.

In 2006 yet another spectacular advance was made, for the first time involving a macroscopic object. Physicists at the Niels Bohr Institute in Copenhagen and the Max Planck Institute in Germany were able to entangle a light beam with a gas of cesium atoms, a feat involving trillions upon trillions of atoms. Then they encoded information contained inside laser pulses and were able to teleport this information to the cesium atoms over a distance of about half a yard. "For the first time," said Eugene Polzik, one of the researchers, quantum teleportation "has been achieved between light-the carrier of information- and atoms."

Teleportation without Entanglement

Progress in teleportation is rapidly accelerating. In 2007 yet another breakthrough was made. Physicists proposed a teleportation method that does not require entanglement. We recall that entanglement is the single most difficult feature of quantum teleportation. Solving this problem could open up new vistas in teleportation.

"We're talking about a beam of about 5,000 particles disappearing from one place and appearing somewhere else," says physicist Aston Bradley of the Australian Research Council Centre of Excellence for Quantum Atom Optics in Brisbane, Australia, who helped pioneer a new method of teleportation.

"We feel that our scheme is closer in spirit to the original fictional concept," he claims. In their approach, he and his colleagues take a beam of rubidium atoms, convert all its information into a beam of light, send this beam of light across a fiber-optic cable, and then reconstruct the original beam of atoms in a distant location. If his claim holds up, this method would eliminate the number one stumbling block to teleportation and open up entirely new ways to teleport increasingly large objects.

In order to distinguish this new method from quantum teleportation, Dr. Bradley has called his method "classical teleportation." (This is a bit misleading, since his method also depends heavily on the quantum theory, but not on entanglement.)

The key to this novel type of teleportation is a new state of matter called a "Bose Einstein condensate," or BEC, which is one of the coldest substances in the entire universe. In nature the coldest temperature is found in outer space; it is 3 R above absolute zero. (This is due to residual heat left over from the big bang, which still fills up the universe.) But a BEC is a *millionth to a billionth* of a degree above absolute zero, a temperature that can be found only in the laboratory.

When certain forms of matter are cooled down to near absolute zero, their atoms all tumble down to the lowest energy state, so that all their atoms vibrate in unison, becoming coherent. The wave functions of all the atoms overlap, so that, in some sense, a BEC is like a gigantic "super atom," with all the individual atoms vibrating in unison. This bizarre state of matter was predicted by Einstein and Satyendranath Bose in 1925, but it would be another seventy years, not until 1995, before a BEC was finally created in the lab at MIT and the University of Colorado.

Here's how Bradley and company's teleportation device works.

First they start with a collection of supercold rubidium atoms in a BEC state. They then apply a beam of matter to the BEC (also made of rubidium atoms). These atoms in the beam also want to tumble down to the lowest energy state, so they shed their excess energy in the form of a pulse of light. This light beam is then sent down a fiber-optic cable. Remarkably the light beam contains all the quantum information necessary to describe the original matter beam (e.g., the location and velocity of all its atoms). Then the light beam hits another BEC, which then converts the light beam into the original matter beam.

This new teleportation method has tremendous promise, since it doesn't involve the entanglement of atoms. But this method also has its problems. It depends crucially on the properties of BECs, which are difficult to create in the laboratory. Furthermore, the properties of BECs are quite peculiar, because they behave as if they were one gigantic atom. In principle, bizarre quantum effects that we see only at the atomic level can be seen with the naked eye with a BEC. This was once thought to be impossible.

The immediate practical application of BECs is to create "atomic lasers." Lasers, of course, are based on coherent beams of photons vibrating in unison. But a BEC is a collection of atoms vibrating in unison, so it's possible to create beams of BEC atoms that are all coherent. In other words, a BEC can create the counterpart of the laser, the atomic laser or matter laser, which is made of BEC atoms. The commercial applications of lasers are enormous, and the commercial applications of atomic lasers could also be just as profound. But because BECs exist only at temperatures hovering just above absolute zero, progress in this field will be slow, albeit steady.

Given the progress we have made, when might we be able to teleport ourselves? Physicists hope to teleport complex molecules in the coming years. After that perhaps a DNA molecule or even a virus may be teleported within decades. There is nothing in principle to prevent teleporting an actual person, just as in the science fiction movies, but the technical problems facing such a feat are truly staggering. It takes some of the finest physics laboratories in the world just to create coherence between tiny photons of light and individual atoms. Creating quantum coherence involving truly macroscopic objects, such as a person, is out of the question for a long time to come. In fact, it will likely take many centuries, or longer, before everyday objects could be teleported-if it's possible at all.

Quantum Computers

Ultimately, the fate of quantum teleportation is intimately linked to the fate of the development of quantum computers. Both use the same quantum physics and the same technology, so there is intense cross-fertilization between these two fields. Quantum computers may one day replace the familiar digital computer sitting on our desks. In fact, the future of the world's economy may one day depend on such computers, so there is enormous commercial interest in these technologies. One-day Silicon Valley could become a Rust Belt, replaced by new technologies emerging from quantum computing.

Ordinary computers compute on a binary system of 0s and Is, called bits. But quantum computers are far more powerful. They can compute on qubits, which can take values between 0 and 1. Think of an atom placed in a magnetic field. It is spinning like a top, so its spin axis can point either up or down. Common sense tells us that the spin of the atom can be either up or down but not both at the same time. But in the strange world of the quantum, the atom is described as the sum of two states, the sum of an atom spinning up and an atom spinning down. In the netherworld of the quantum, every object is described by the sum of all possible states. (If large objects, like cats, are described in this quantum fashion, it means that you have to add the wave function of a live cat to that of a dead cat, so the cat is neither dead nor alive.)

Now imagine a string of atoms aligned in a magnetic field, with the spin aligned in one fashion. If a laser beam is shone on this string of atoms the laser beam will bounce off this collection of atoms, flipping the spin axis of some of the atoms. By measuring the difference between the incoming and outgoing laser beam, we have accomplished a complicated quantum "calculation," involving the flipping of many spins.

Quantum computers are still in their infancy. The world's record for a quantum computation is 3 x 5 = 15, hardly a calculation that will supplant today's supercomputers. Quantum teleportation and quantum computers both share the same fatal weakness: maintaining coherence for large collections of atoms. If this problem can be solved, it would be an enormous breakthrough in both fields.

The CIA and other secret organizations are intensely interested in quantum computers. Many of the world's secret codes depend on a "key," which is a very large integer, and one's ability to factor it into prime numbers. If the key is the product of two numbers, each with one hundred digits, then it might take a digital computer more than a hundred years to find these two factors from scratch. Such a code is essentially unbreakable today.

But in 1994 Peter Shor of Bell Labs showed that factoring large numbers could be child's play for a quantum computer. This discovery immediately piqued the interest of the intelligence community. In principle a quantum computer could break all the world's codes, throwing the security of today's computer systems into total disorder. The first country that is able to build such a system would be able to unlock the deepest secrets of other nations and organizations.

Some scientists have speculated that in the future the world's economy might depend on quantum computers. Silicon-based digital computers are expected to reach their physical limits in terms of increased computer power sometime after 2020. A new, more powerful family of computers might be necessary if technology is going to continue to advance. Others are exploring the possibility of reproducing the power of the human brain via quantum computers.

The stakes, therefore, are very high. If we can solve the problem of coherence, not only might we be able to solve the challenge of teleportation; we might also have the ability to advance technology of all kinds in untold ways via quantum computers.

As I pointed out earlier, coherence is extraordinarily difficult to maintain in the lab. The tiniest vibration could upset the coherence of two atoms and destroy the computation. Today it is very difficult to maintain coherence in more than just a handful of atoms. Atoms that are originally in phase begin to decohere within a matter of nanoseconds to, at best, a second. Teleportation must be done very rapidly, before the atoms begin to decohere, thus placing another restriction on quantum computation and teleportation.

In spite of these challenges, David Deutsch of Oxford University believes that these problems can be overcome: "With luck, and with the help of recent theoretical advances, [a quantum computer] may take a lot less than 50 years It would be an entirely new way of harnessing nature."

So teleportation exists at the atomic level, and we may eventually teleport complex and even organic molecules within a few decades. But the teleportation of a macroscopic object will have to wait for several decades to centuries beyond that, or longer, if indeed it is even possible. Therefore, teleporting complex molecules, perhaps even a virus or a living cell, qualifies as a Class I impossibility, one that should be possible within this century. But teleporting a human being, although it is allowed by the laws of physics, may take many centuries beyond that, assuming it is possible at all. Hence I would qualify that kind of teleportation as a Class I impossibility.

3: Faster than light

Science fiction? Undoubtedly. But could it be based on scientific fact? Perhaps. Faster-than-light travel has always been a staple of science fiction, but recently physicists have given serious thought to this possibility.

According to Einstein, the speed of light is the ultimate speed limit in the universe. Even our most powerful atom smashers, which can create energies found only at the center of exploding stars or the big bang itself, cannot hurl subatomic particles at a rate faster than the speed of light. Apparently the speed of light is the ultimate traffic cop in the universe. If so, any hope of our reaching the distant galaxies seems to be dashed.

Or maybe not . . .

Einstein And Relativity:

Albert Einstein proposed his celebrated special theory of relativity in 1905. At the heart of his theory was a picture that even children can understand. His theory was the culmination of a dream he had had since the age of sixteen, when he asked the fateful question: what happens if you outrace a light beam? As a youth, he knew that Newtonian mechanics described the motion of objects on the Earth and in the heavens, and that Maxwell's theory described light. These were the two pillars of physics.

The essence of Einstein's genius was that he recognized that these two pillars were in contradiction. One of them must fall.

According to Newton, you could always outrace a light beam, since there was nothing special about the speed of light. This meant that the light beam must remain stationary as you raced alongside. But as a youth Einstein realized that no one had ever seen a light wave that was totally stationary, that is, like a frozen wave. Hence Newton's theory did not make sense.

Finally, as a college student in Zurich studying Maxwell's theory, Einstein found the answer. He discovered something that even Maxwell did not know: that the speed of light was a constant, no matter how fast you moved. If you raced toward or away from a light beam, it still traveled at the same velocity, but this trait violates common sense. Einstein had found the answer to his childhood question: you can never race alongside a light beam, since it always moves away from you at a constant speed, no matter how fast you move.

But Newtonian mechanics was a tightly constrained system: like pulling on a loose thread, the entire theory could unravel if you made the smallest change in its assumptions. In Newton's theory the passage of time was uniform throughout the universe. One second on the Earth was identical to one second on Venus or Mars. Similarly, meter sticks placed on the Earth had the same length as meter sticks on Pluto. But if the speed of light was always constant no matter how fast you moved, there would need to be a major shakeup in our understanding of space and time. Profound distortions of space and time would have to occur to preserve the constancy of the speed of light.

According to Einstein, if you were in a speeding rocket ship, the passage of time inside that rocket would have to slow down with respect to someone on Earth. Time beats at different rates, depending on how fast you move. Furthermore, the space within that rocket ship would get compressed, so that meter sticks could change in length, depending on your speed. And the mass of the rocket would increase as well. If we were to peer into the rocket with our telescopes, we would see clocks inside the rocket running slowly, people moving in slow motion, and the people would appear flattened.

In fact, if the rocket were traveling at the speed of light, time would apparently stop inside the rocket, the rocket would be compressed to nothing, and the mass of the rocket would be infinite. Since none of these observations make any sense, Einstein stated that nothing can break the light barrier. (Because an object gets heavier the faster it moves; this means that the energy motion is being converted to mass. The precise amount of energy that turns into mass is easy to calculate, and we arrive at the celebrated equation $E = mc^2$ in just a few lines.)

Since Einstein derived his famous equation, literally millions of experiments have confirmed his revolutionary ideas. For example, the GPS system, which can locate your position on the Earth to within a few feet, would fail unless one added in corrections due to relativity. The clocks on the GPS actually change as they speed above the Earth, as Einstein predicted.

The most graphic illustration of this concept is found in atom smashers, in which scientists accelerate particles to nearly the speed of light. At the gigantic CERN accelerator, the Large Hadron Collider, outside Geneva, Switzerland, protons are accelerated to trillions of electron volts, and they move very close to the speed of light.

To a rocket scientist, the light barrier is not much of a problem yet, since rockets can barely travel beyond a few tens of thousands of miles per hour. But within a century or two, when rocket scientists seriously contemplate sending probes to the nearest star (located over 4 lightyears from Earth), the light barrier could gradually become a problem.

Loopholes in Einstein’s Theory:

Over the decades, physicists have tried to find loopholes in Einstein's famous dictum. Some loopholes have been found, but most are not very useful. For example, if one sweeps a flashlight across the heavens, in principle the image of the light beam can exceed the speed of light. In a few seconds, the image of the flashlight moves from one point on the horizon to the opposite point, over a distance that can stretch over hundreds of light-years. But this is of no importance, since no information can be transmitted faster than light in this fashion. The image of the light beam has exceeded the speed of light, but the image carries no energy or information.

Similarly, if we have a pair of scissors, the point at which the blades cross each other moves faster the farther you are from the joining point. If we imagine scissors that are a light-year long, then by closing the blades the crossing point can travel faster than light. (Again, this is not important since the crossing point carries no energy or information.)

Likewise, as I mentioned in Chapter Two, the EPR experiment enables one to send information at speeds faster than the speed of light. (In this experiment, we recall, two electrons are vibrating in unison and then are sent speeding in opposite directions. Because these electrons are coherent, information can be sent between them at speeds faster than the speed of light, but this information is random and hence is useless. EPR machines, hence, cannot be used to send probes to the distant stars.)

To a physicist, the most important loophole came from Einstein himself, who created the general theory of relativity in 1915, a theory that is more powerful than the special theory of relativity. The seeds of general relativity were planted when Einstein considered a children's merry-go-round. As we saw earlier, objects shrink as they approach the speed of light. The faster you move, the more you are squeezed. But in a spinning disk, the outer circumference moves faster than the center. (The center, in fact, is almost stationary.) This means that a ruler stick placed on the rim must shrink, while a ruler placed at the center remains nearly the same, so the surface of the merry-go-round is no longer flat, but is curved. Thus acceleration has the effect of curving space and time on the merry-go-round.

In the general theory of relativity, space-time is a fabric that can stretch and shrink. Under certain circumstances the fabric may stretch faster than the speed of light. Think of the big bang, for example, when the universe was born in a cosmic explosion 13.7 billion years ago. One can calculate that the universe originally expanded faster than the speed of light. (This action does not violate special relativity, since it was empty space-the space between stars-that was expanding, not the stars themselves. Expanding space does not carry any information.)

The important point is that special relativity applies only locally, that is, in your nearby vicinity. In your local neighborhood (e.g., the solar system), special relativity holds, as we confirm with our space probes. But globally (e.g., on cosmological scales involving the universe) we must use general relativity instead.

In general relativity, space-time becomes a fabric, and this fabric can stretch faster than light. It can also allow for "holes in space" in which one can take shortcuts through space and time.

Given these caveats, perhaps one way to travel faster than light is to invoke general relativity. There are two ways in which this might be done.

1. *Stretching space.* If you were to stretch the space behind you and contact the space in front of you, then you would have the illusion of having moved faster than light. In fact, you would not have moved at all. But since space has been deformed, it means you can reach the distant stars in a twinkling of an eye.
2. *Ripping space.* In 1935 Einstein introduced the concept of a wormhole. Imagine the Looking Glass of Alice, a magical device that connects the countryside of Oxford to Wonderland. The wormhole is a device that can connect two universes. in school, we learned that the shortest distance between two points is a straight line. But this is not necessarily true, because if we curled a sheet of paper until two points touched, then we would see that the shortest distance between two points is actually a wormhole.

As physicist Matt Visser of Washington University says, "The relativity community has started to think about what would be necessary to take something like warp drive or wormholes out of the realm of science fiction."[10]

Sir Martin Rees, Royal Astronomer of Great Britain, even says, "Wormholes, extra dimensions, and quantum computers open up speculative scenarios that could transform our entire universe eventually into a 'living cosmos.' "[11]

The Alcubierre Drive And Negative Energy:

The best example of stretching space is the Alcubierre drive, proposed by physicist Miguel Alcubierre in 1994 using Einstein's theory of gravity. It is quite similar to the propulsion system seen in *Star Trek.* The pilot of such a starship would be seated inside a bubble (called a "warp bubble") in which everything seemed to appear normal, even as the spacecraft broke the light barrier. In fact, the pilot would think that he was at rest. Yet outside the warp bubble extreme distortions of space-time would occur as the space in front of the warp bubble was compressed. There would be no time dilation, so time would pass normally inside the warp bubble.

Alcubierre speculates that a journey in his proposed starship would resemble a journey taken on the *Millennium Falcon* in *Star Wars.* "My guess is they would probably see something very similar to that. In front of the ship, the stars would become long lines, streaks. In back, they wouldn't see anything-just black-because the light of the stars couldn't move fast enough to catch up with them," he says.

The key to the Alcubierre drive is the energy necessary to propel the spacecraft forward at faster-than-light velocities. Normally physicists begin with a positive amount of energy in order to propel a starship, which always travels slower than the speed of light. To move beyond this strategy so as to be able to travel faster than the speed of light one would need to change the fuel. A straightforward calculation shows that you would need "negative mass" or "negative energy," perhaps the most exotic entities in the universe, if they exist. Traditionally, physicists have dismissed negative energy and negative mass as science fiction. But we now see that they are indispensable for faster than- light travel, and they might actually exist.

Scientists have looked for negative matter in nature, but so far without success. (Antimatter and negative matter are two entirely different things. The first exists and has positive energy, but a reversed charge. Negative matter has not yet been proven to exist.) Negative matter would be quite peculiar, because it would be lighter than nothing. In fact, it would float. If negative matter existed in the early universe, it would have drifted into outer space. Unlike meteors that come crashing down onto planets, drawn by a planet's gravity, negative matter would shun planets. It would be repelled, not attracted, by large bodies

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[10] Special Relativity and Motions Faster than Light,2004, Fayngold, Moses Cramer, John G

[11] Special Relativity and Motions Faster than Light,2004, Fayngold, Moses Cramer, John G

such as stars and planets. Hence, although negative matter might exist, we expect to find it only in deep space, certainly not on Earth.

One proposal to find negative matter in outer space involves using the phenomenon called "Einstein lenses." When light travels around a star or galaxy its path is bent by its gravity, according to general relativity. In 1912 (even before Einstein fully developed general relativity) he predicted that a galaxy might be able to act like the lens of a telescope. Light from a distant object moving around a nearby galaxy would converge as it passed around the galaxy, like a lens, forming a characteristic ring pattern when the light finally reached the Earth. These phenomena are now called "Einstein rings." In 1979 the first of these Einstein lenses was observed in outer space. Since then, Einstein lenses have become an indispensable tool for astronomers. (For example, it was once thought that it would be impossible to locate "dark matter" in outer space. [Dark matter is a mysterious substance that is invisible but has weight. It surrounds the galaxies and is perhaps ten times as plentiful as ordinary visible matter in the universe.] But NASA scientists have been able to construct maps of dark matter since dark matter bends light as the light passes through, in the same way that glass bends light.)

Therefore, it should be possible to use Einstein lenses to search for negative matter and wormholes in outer space. They should bend light in a peculiar way, which should be visible with the Hubble Space Telescope. So far, Einstein lenses have not detected the image of negative matter or wormholes in outer space, but the search is continuing. If one day the Hubble Space Telescope detects the presence of negative matter or a wormhole via Einstein lenses, it could set off a shock wave in physics.

Negative energy is different from negative matter in that it actually exists, but only in minute quantities. In 1933 Hendrik Casimir made a bizarre prediction using the laws of the quantum theory. He claimed that two uncharged parallel metal plates will attract each other, as if by magic. Normally parallel plates are stationary, since they lack any net charge. But the vacuum between the two parallel plates is not empty, but full of "virtual particles," which dart in and out of existence.

For brief periods of time, electron-antielectron pairs burst out of nothing, only to be annihilated and disappear back into the vacuum. Ironically, empty space, which was once thought to be devoid of anything, now turns out to be churning with quantum activity. Normally tiny bursts of matter and antimatter would seem to violate the conservation of energy. But because of the uncertainty principle, these tiny violations are incredibly short-lived, and on average energy is still conserved.

Casimir found that the cloud of virtual particles will create a net pressure in the vacuum. The space between the two parallel plates is confined, and hence the pressure is low. But the pressure outside the plates is unconfined and larger, and hence there will be a net pressure pushing the plates together.

Normally the state of zero energy occurs when these two plates are at rest and sitting far apart from each other. But as the plates come closer together, you can extract energy out of them. Thus, because kinetic energy has been taken out of the plates, the energy of the plates is less than zero.

This negative energy was actually measured in the laboratory in 1948, and the results confirmed Casimir's prediction. Thus, negative energy and the Casimir effect are no longer science fiction but established fact. The problem, however, is that the Casimir effect is quite small; it takes delicate, state-of-the-art measuring equipment to detect this energy in the laboratory. (In general, the Casimir energy is proportional to the inverse fourth power of the distance of separation between the plates. This means that the smaller the distance of separation, the larger the energy.) The Casimir effect was measured precisely in 1996 by Steven Lamoreaux at the Los Alamos National Laboratory, and the attractive force is $1 / 30000$ the weight of an ant.

Since Alcubierre first proposed his theory, physicists have discovered a number of strange properties. The people inside the starship are causally disconnected from the outside world. This means that you cannot simply press a button at will and travel faster than light. You cannot communicate through the bubble. There has to be a preexisting "highway" through space and time, like a series of trains passing by on a regular timetable. In this sense, the starship would not be an ordinary ship that can change directions and speeds at will. The starship would actually be like a passenger car riding on a preexisting "wave" of compressed space, coasting along a preexisting corridor of warped space-time. Alcubierre speculates, "We would need a series of generators of exotic matter along the way, like a highway, that manipulate space for you in a synchronized way."

Actually, even more bizarre types of solutions to Einstein's equations can be found. Einstein's equations state that if you are given a certain amount of mass or energy, you can compute the warping of space-time that the mass or energy will generate (in the same way that if you throw a rock into a pond, you can calculate the ripples that it will create). But you can also run the equations backward. You can start with a bizarre space-time, the kind found in episodes of *The Twilight Zone.* (In these universes, for example, you can open up a door and find yourself on the moon. You can run around a tree and find yourself backward in time, with your heart on the right side of your body.) Then you calculate the distribution of matter and energy associated with that particular space-time. (This means that if you are given a bizarre collection of waves on the surface of a pond, you can work backward and calculate the distribution of rocks necessary to produce these waves). This was, in fact, the way in which Alcubierre derived his equations. He began with a space-time consistent with going faster than light, and then he worked backward and calculated the energy necessary to produce it.

Wormholes And Black Holes:

Besides stretching space, the second possible way to break the light barrier is by ripping space, via wormholes, passageways that connect two universes. In fiction, the first mention of a wormhole came from Oxford mathematician Charles Dodgson, who wrote *Through the Looking Glass* under the pen name Lewis Carroll. The Looking Glass of Alice is the wormhole, connecting the countryside of Oxford with the magical world of Wonderland. By placing her hand through the Looking Glass, Alice can be transported instantly from one universe to the next. Mathematicians call these "multiply connected spaces."

The concept of wormholes in physics dates back to 1916, one year after Einstein published his epic general theory of relativity.[12] Physicist Karl Schwarzschild, then serving in the Raiser's army, was able to solve Einstein's equations exactly for the case of a single point like star. Far from the star, its gravitational field was very similar to that of an ordinary star, and in fact Einstein used Schwarzschild's solution to calculate the deflection of light around a star. Schwarzschild's solution had an immediate and profound impact on astronomy, and even today it is one of the best-known solutions of Einstein's equations. For generations, physicists used the gravitational field around this point like star as an approximation to the field around a real star, which has a finite diameter.

But if you took this pointlike solution seriously, then lurking at the center of it was a monstrous pointlike object that has shocked and amazed physicists for almost a century-a black hole. Schwarzschild's solution for the gravity of a pointlike star was like a Trojan Horse. On the outside it looked like a gift from heaven, but on the inside there lurked all sorts of demons and ghosts. But if you accepted one, you had to accept the other. Schwarzschild's solution showed that as you approached this pointlike star, bizarre things happened. Surrounding the star was an invisible sphere (called the "event horizon") that was a point of no return. Everything checked in, but nothing could check out, like a Roach Motel. Once you passed through the event horizon, you never came back. (Once inside the event horizon, you would have to travel faster than light to escape back outside the event horizon, and that would be impossible.)

As you approached the event horizon, your atoms would be stretched by tidal forces. The gravity felt by your feet would be much greater than the gravity felt by your head, so you would be "spaghettified" and then ripped apart. Similarly, the atoms of your body would also be stretched and torn apart by gravity.

To an outside observer watching you approach the event horizon, it would appear that you were slowing down in time. In fact, as you hit the event horizon, it would appear that time had stopped!

Furthermore, as you fell past the event horizon, you would see light that has been trapped and circulating around this black hole for billions of years. It would seem as if you were watching a motion picture film, detailing the entire history of the black hole, going back to its very origin.

And finally, if you could fall straight through to the black hole, there would be another universe on the other side. This is called the Einstein-Rosen Bridge, first introduced by Einstein in 1935; it is now called a wormhole.

Einstein and other physicists believed a star could never evolve naturally into such a monstrous object. In fact, in 1939 Einstein published a paper showing that a circulating mass of gas and dust will never condense into such a black hole. So although there was a wormhole lurking in the center of a black hole,

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[12] Black Holes and Baby universe and other and other essays,1993,Stephen Hawking.

he was confident that such a strange object could never form by natural means. In fact, astrophysicist Arthur Eddington once said that there should "be a law of nature to prevent a star from behaving in this absurd way." In other words, the black hole was indeed a legitimate solution of Einstein's equations, but there was no known mechanism that could form one by natural means.

All this changed with the advent of a paper by J. Robert Oppenheimer and his student Hartland Snyder, written that same year, showing that black holes can indeed be formed by natural means. They assumed that a dying star had used up its nuclear fuel and then collapsed under gravity, so that it imploded under its own weight. If gravity could compress the star to within its event horizon, then nothing known to science could prevent gravity from squeezing the star to a point-particle, the black hole.

The next breakthrough came in 1963, when New Zealand mathematician Roy Kerr examined perhaps the most realistic example of a black hole. Objects spin faster as they shrink, in much the same way that skaters spin faster when they bring in their arms close to their body. As a result, black holes should be spinning at fantastic rates.

Kerr found that a spinning black hole would not collapse into a pointlike star, as Schwarzschild assumed, but would collapse into a spinning ring. Anyone unfortunate enough to hit the ring would perish; but someone falling into the ring would not die, but would actually fall through. But instead of winding up on the other side of the ring, he or she would pass through the Einstein-Rosen Bridge and wind up in another universe. In other words, the spinning black hole is the rim of Alice's Looking Glass.

If he or she were to move around the spinning ring a second time, he or she would enter yet another universe. In fact, repeated entry into the spinning ring would put a person in different parallel universes, much like hitting the "up" button on an elevator. In principle, there could be an infinite number of universes, each stacked on top of each other. "Pass through this magic ring and-presto! -you're in a completely different universe where radius and mass are negative!" Kerr wrote.

There is an important catch, however. Black holes are examples of "nontransversable wormholes"; that is, passing through the event horizon is a one-way trip. Once you pass through the event horizon and the Kerr ring, you cannot go backward through the ring and out through the event horizon.

But in 1988 Rip Thorne and colleagues at Cal Tech found an example of a transversable wormhole, that is, one through which you could pass freely back and forth. In fact, for one solution, the travel through a wormhole would be no worse than riding on an airplane.

Normally gravity would crush the throat of the wormhole, destroying the astronauts trying to reach the other side. That is one reason that faster-than-light travel through a wormhole is not possible. But the repulsive force of negative energy or negative mass could conceivably keep the throat open sufficiently long to allow astronauts a clear passage. In other words, negative mass or energy is essential for both the Alcubierre drive and the wormhole solution.

In the last few years an astonishing number of exact solutions have been found to Einstein's equations that allow for wormholes. But do wormholes really exist, or are they just a figment of mathematics?

There are several major problems facing wormholes.

First, to create the violent distortions of space and time necessary to travel through a wormhole, one would need fabulous amounts of positive and negative matter, on the order of a huge star or a black hole. Matthew Visser, a physicist at Washington University, estimates that the amount of negative energy you would need to open up a 1-meter wormhole is comparable to the mass of Jupiter, except that it would need to be negative. He says, "You need about minus one Jupiter mass to do the job. Just manipulating a positive Jupiter mass of energy is already pretty freaky, well beyond our capabilities into the foreseeable future."

Rip Thorne of the California Institute of Technology speculates that "it will turn out that the laws of physics do allow sufficient exotic matter in wormholes of human size to hold the wormhole open. But it will also turn out that the technology for making wormholes and holding them open is unimaginably far beyond the capabilities of our human civilization."

Second, we do not know how stable these wormholes would be. The radiation generated by these wormholes might kill anyone who enters. Or perhaps the wormholes would not be stable at all, closing as soon as one entered them.

Third, light beams falling into the black hole would be blue shifted; that is, they would attain greater and greater energy as they came close to the event horizon. In fact, at the event horizon itself, light is technically infinitely blue shifted, so the radiation from this in falling energy could kill anyone in a rocket.

Let us discuss these problems in some detail. One problem is to amass enough energy to rip the fabric of space and time. The simplest way to do this is to compress an object until it becomes smaller than its "event horizon." For the sun, this means compressing it down to about 2 miles in diameter, whereupon it will collapse into a black hole. (The Sun's gravity is too weak to compress it naturally down to 2 miles, so our sun will never become a black hole. In principle, this means that anything, even you, can become a black hole if you were sufficiently compressed. This would mean compressing all the atoms of your body to smaller than subatomic distances-a feat that is beyond the capabilities of modern science.)

A more practical approach would be to assemble a battery of laser beams to fire an intense beam at a specific spot. Or to build a huge atom smasher to create two beams, which would then collide with each other at fantastic energies, sufficient to create a small tear in the fabric of space-time.

Planck Energy and Particle Accelerators:

One can calculate the energy necessary to create an instability in space and time: it is of the order of the Planck energy, or 1019 billion electron volts. This is truly an unimaginably large number, a quadrillion times larger than the energy attainable with today's most powerful machine, the Large Hadron Collider (LHC), located outside Geneva, Switzerland. The LHC is capable of swinging protons in a large "doughnut" until they reach energies of trillions of electron volts, energies not seen since the big bang. But even this monster of a machine falls far short of producing energy anywhere near the Planck energy.

The next particle accelerator after the LHC will be the International Linear Collider (ILC). Instead of bending the path of subatomic particles into a circle, the ILC will shoot them down a straight path. Energy will be injected as the particles move along this path, until they attain unimaginably large energies. Then a beam of electrons will collide with antielectrons, creating a huge burst of energy. The ILC will be 30 to 40 kilometers long, or ten times the length of the Stanford Linear Accelerator, currently the largest linear accelerator. If all goes well, the ILC is due to be completed sometime in the next decade.

The energy produced by the ILC will be 0.5 to 1.0 trillion electron volts-less than the 14 trillion electron volts of the LHC, but this is deceptive. (In the LHC, the collisions between the protons take place between the constituent quarks making up the proton. Hence the collisions involving the quarks are less than 14 trillion electron volts. That is why the ILC will produce collision energies larger than those of the LHC.) Also, because the electron has no known constituent, the dynamics of the collisions between electron and antielectron are simpler and cleaner.

But realistically, the ILC, too, falls far short of being able to open up a hole in space-time. For that, you would need an accelerator a quadrillion times more powerful. For our Type 0 civilization, which uses dead plants for fuel (e.g., oil and coal), this technology is far beyond anything we can muster. But it may become possible for a Type III civilization.

Remember, a Type III civilization, which is galactic in its use of energy, consumes 10 billion times more energy than a Type II civilization, whose consumption is based on the energy of a single star. And a Type II civilization in turn consumes 10 billion times more energy than a Type I civilization, whose consumption is based on the energy of a single planet. In one hundred to two hundred years, our feeble Type 0 civilization will reach Type I status.

Given that projection, we are a long, long way from being able to achieve the Planck energy. Many physicists believe that at extremely tiny distances, at the Planck distance of 103 3 centimeters, space is not empty or smooth but becomes "foamy"; it is frothing with tiny bubbles that constantly pop into existence, collide with other bubbles, and then vanish back into the vacuum. These bubbles that dart in and out of the vacuum are "virtual universes," very similar to the virtual particles of electrons and antielectrons that pop into existence and then disappear.

Normally, this quantum space-time "foam" is completely invisible to us. These bubbles form at such tiny distances that we cannot observe them. But quantum physics suggests that if we concentrate enough energy at a single point, until we reach the Planck energy, these bubbles can become large. Then we would see space-time frothing with tiny bubbles, each bubble a wormhole connected to a "baby universe."

In the past these baby universes were considered an intellectual curiosity, a strange consequence of pure mathematics. But now physicists are seriously thinking that our universe might have originally started off as one of these baby universes.

Such thinking is sheer speculation, but the laws of physics allow for the possibility of opening a hole in space by concentrating enough energy at a single point, until we access the space-time foam and wormholes emerge connecting our universe to a baby universe.

Achieving a hole in space would, of course, require major breakthroughs in our technology, but again, it might be possible for a Type III civilization. For example, there have been promising developments in something called a "Wakefield tabletop accelerator." Remarkably, this atom smasher is so small that it can be placed on top of a table yet generate billions of electron volts of energy. The Wakefield tabletop accelerator works by firing lasers onto charged particles, which then ride on the energy of that laser. Experiments done at the Stanford Linear Accelerator Center, the Rutherford Appleton Laboratory in England, and the École Polytechnique in Paris show that enormous accelerations are possible over small distances using laser beams and plasma to inject energy.

Yet another breakthrough was made in 2007, when physicists and engineers at the Stanford Linear Accelerator Center, UCLA, and USC demonstrated that you can double the energy of a huge particle accelerator in just 1 meter. They started with a beam of electrons that are fired down a 2-mile-long tube in Stanford, reaching an energy of 42 billion electron volts. Then these high-energy electrons were sent through an "afterburner," which consisted of a plasma chamber only 88 centimeters long, where the electrons pick up an additional 42 billion electron volts, doubling their energy. (The plasma chamber is filled with lithium gas. As the electrons pass through the gas, they create a plasma wave that creates a wake. This wake in turn flows to the back of the electron beam and then shoves it forward, giving it an extra boost.) In this stunning achievement, the physicists improved by a factor of three thousand the previous record for the amount of energy per meter they could accelerate an electron beam. By adding such "afterburners" to existing accelerators, one might in principle double their energy, almost for free.

Today the world record for a Wakefield tabletop accelerator is 200 billion electron volts per meter. There are numerous problems scaling this result to longer distances (such as maintaining the stability of the beam as laser power is pumped into it). But assuming that we could maintain a power level of 200 billion electron volts per meter, this means that an accelerator capable of reaching the Planck energy would have to be 10 light-years long. This is well within the capability of a Type III civilization.

Wormholes and stretched space may give us the most realistic way of breaking the light barrier. But it is not known if these technologies are stable; if they are, it would still take a fabulous amount of energy, positive or negative, to make them work.

Perhaps an advanced Type III civilization might already have this technology. It might be millennia before we can even think about harnessing power on this scale. Because there is still controversy over the fundamental laws governing the fabric of space-time at the quantum level, I would classify this as a Class II impossibility.

4: Time Travel

Changing The Past:

Time is one of the great mysteries of the universe. We are all swept up in the river of time against our will. Around AD 400, Saint Augustine wrote extensively about the paradoxical nature of time: "How can the past and future be, when the past no longer is, and the future is not yet? As for the present, if it were always present and never moved on to become the past, it would not be time, but eternity." [13]If we take Saint Augustine's logic further, we see that time is not possible, since the past is gone, the future does not exist, and the present exists only for an instant.

Like Saint Augustine, all of us have at some time wondered about the strange nature of time and how it differs from space. If we can move forward and backward in space, why not in time? All of us have also

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[13] Time travel and warp drives: a scientific guide to shortcuts through time and space,2012, Everett, Allen Roman, Thomas

wondered what the future may hold for us, in the time beyond our years. Humans have a finite lifetime, but we are intensely curious about events that will happen long after we are gone.

Although our longing to travel in time is probably as ancient as humanity, apparently the very first written time travel story is *Memoirs of the Twentieth Century,* written in 1733 by Samuel Madden, about an angel from the year 1997 who journeys over 250 years into the past to give documents to a British ambassador that describe the world of the future.

There would be many more such stories. The 1838 short story "Missing One's Coach: An Anachronism," written anonymously, is about a person waiting for a coach who suddenly finds himself a thousand years in the past. He meets a monk from an ancient monastery and tries to explain to him how history will progress for the next thousand years. Afterward he suddenly finds himself just as mysteriously transported back to the present, except that he has missed his coach.

Even the 1843 Charles Dickens novel, *A Christmas Carol,* is a kind of time travel story, since Ebenezer Scrooge is taken into the past and into the future to witness the world before the present and after his death.

In American literature the first appearance of time travel dates back to Mark Twain's 1889 novel, *A Connecticut Yankee in King Arthur's Court.* A nineteenth-century Yankee is wrenched backward through time to wind up in Ring Arthur's court in AD 528. He is taken prisoner and is about to be burned at the stake, but then he declares he has the power to blot out the sun, knowing that an eclipse of the sun would happen on that very day. When the sun is eclipsed, the mob is horrified and agrees to set him free and grant him privileges in exchange for the return of the sun.

But the first serious attempt to explore time travel in fiction was H. G. Wells's classic *The Time Machine,* in which the hero is sent hundreds of thousands of years into the future. In that distant future, humanity itself has genetically split into two races, the menacing Moorlocks who maintain the grimy underground machines, and the useless, childlike Eloi who dance in the sunlight in the world above, never realizing their awful fate (to be eaten by the Moorlocks).

Since then, time travel has become a regular feature of science fiction, from *Star Trek* to *Back to the Future.* In *Superman I,* when Superman learns that Lois Lane has died, he decides in desperation to turn back the hands of time, rocketing himself around the Earth, faster than the speed of light, until time itself goes backward. The Earth slows down, stops, and eventually spins in the opposite direction, until all clocks on the Earth beat backward. Floodwaters rage backward, broken dams miraculously heal themselves, and Lois Lane comes back from the dead.

From the perspective of science, time travel was impossible in Newton's universe, where time was seen as an arrow. Once fired, it could never deviate from its past One second on the Earth was one second throughout the universe. This conception was overthrown by Einstein, who showed that time was more like a river that meandered across the universe, speeding up and slowing down as it snaked across stars and galaxies. So one second on the Earth is not absolute; time varies when we move around the universe.

As I discussed earlier, according to Einstein's special theory of relativity, time slows down inside a rocket the faster it moves. Science fiction writers have speculated that if you could break the light barrier, you could go back in time. But this is not possible, since you would have to have infinite mass in order to reach the speed of light. The speed of light is the ultimate barrier for any rocket. The crew of the *Enterprise* in *Star Trek IV: The Voyage Home* hijacked a Rlingon spaceship and used it to whip around the sun like a slingshot and break the light barrier to wind up in San Francisco in the 1960s. But this defies the laws of physics.

Nonetheless, time travel to the future is possible, and has been experimentally verified millions of times. The journey of the hero of *The Time Machine* into the far future is actually physically possible. If an astronaut were to travel near the speed of light, it might take him, say, one minute to reach the nearest stars. Four years would have elapsed on the Earth, but for him only one minute would have passed, because time would have slowed down inside the rocket ship. Hence he would have traveled four years into the future, as experienced here on Earth. (Our astronauts actually take a short trip into the future every time they go into outer space. As they travel at 18,000 miles per hour above the Earth, their clocks beat a tiny bit slower than clocks on the Earth. Hence, after a yearlong mission on the space station, they have actually journeyed a fraction of a second into the future by the time they land back on Earth. The world record for traveling into the future is currently held by Russian cosmonaut Sergei Avdeyev, who orbited for 748 days and was hence hurled .02 seconds into the future.)

So a time machine that can take us into the future is consistent with Einstein's special theory of relativity. But what about going backward in time?

If we could journey back into the past, history would be impossible to write. As soon as a historian recorded the history of the past, someone could go back into the past and rewrite it. Not only would time machines put historians out of business, but they would enable us to alter the course of time at will. If, for example, we were to go back to the era of the dinosaurs and accidentally step on a mammal that happens to be our ancestor, perhaps we would accidentally wipe out the entire human race. History would become an unending, madcap Monty Python episode, as tourists from the future trampled over historic events while trying to get the best camera angle.

Time Travel: Physicist’s playground

Perhaps the person who has distinguished himself the most on the dense mathematical equations of black holes and time machines is cosmologist Stephen Hawking. Unlike other students of relativity who often distinguish themselves in mathematical physics at an early age, Hawking was actually not an outstanding student as a youth. He was obviously extremely bright, but his teachers would often notice that he was not focused on his studies and never lived up to his full potential. But a turning point came in 1962, after he graduated from Oxford, when he first began to notice the symptoms of ALS (amyotrophic lateral sclerosis, or Lou Gehrig's disease). He was rocked by the news that he was suffering from this incurable motor neuron disease that would rob him of all motor functions and likely soon kill him. At first the news was extremely upsetting. What would be the use of getting a Ph.D. if he was going to die soon anyway?

But once he got over the initial shock he became focused for the first time in his life. Realizing that he did not have long to live, he began to ferociously tackle some of the most difficult problems in general relativity. In the early 1970s he published a landmark series of papers showing that "singularities" in Einstein's theory (where the gravitational field becomes infinite, like at the center of black holes and at the instant of the big bang) were an essential feature of relativity and could not be easily dismissed (as Einstein thought). In 1974 Hawking also proved that black holes are not entirely black, but gradually emit radiation, now known as Hawking radiation, because radiation can tunnel through the gravity field of even a black hole. This paper was the first major application of the quantum theory to relativity theory, and it represents his best known work.

In 1990 Hawking read papers of his colleagues proposing their version of a time machine, and he was immediately skeptical. His intuition told him that time travel was not possible because there are no tourists from the future. If time travel were as common as taking a Sunday picnic in the park, then time travelers from the future should be pestering us with their cameras, asking us to pose for their picture albums.

Hawking also raised a challenge to the world of physics. There ought to be a law, he proclaimed, making time travel impossible. He proposed a "Chronology Protection Conjecture" to ban time travel from the laws of physics in order to "make history safe for historians."

The embarrassing thing, however, was that no matter how hard physicists tried, they could not find a law to prevent time travel. Apparently time travel seems to be consistent with the known laws of physics. Unable to find any physical law that makes time travel impossible, Hawking recently changed his mind. He made headlines in the London papers when he said, "Time travel may be possible, but it is not practical."

Once considered to be fringe science, time travel has suddenly become a playground for theoretical physicists. Physicist Rip Thorne of Cal Tech writes, "Time travel was once solely the province of science fiction writers. Serious scientists avoided it like the plague-even when writing fiction under pseudonyms or reading it in privacy. How times have changed! One now finds scholarly analyses of time travel in serious scientific journals, written by eminent theoretical physicists ... Why the change? Because we physicists have realized that the nature of time is too important an issue to be left solely in the hands of science fiction writers."

The reason for all this confusion and excitement is that Einstein's equations allow for many kinds of time machines. (Whether they will survive the challenges from the quantum theory, however, is still in doubt.) In Einstein's theory, in fact, we often encounter something called "closed time-like curves," which is the technical term for paths that allow for time travel into the past. If we followed the path of a closed time-like curve, we would set out on a journey and return before we left.[14]

The first time machine involves a wormhole. There are many solutions of Einstein's equations that connect two distant points in space. But since space and time are intimately intertwined in Einstein's theory, this same wormhole can also connect two points in time. By falling down the wormhole, you could journey (at least mathematically) into the past. Conceivably, you could then journey to the original starting point and meet yourself before you left. But as we mentioned in the previous chapter, passing through the wormhole at the center of a black hole is a one-way trip. As physicist Richard Gott has said, "I don't think there's any question that a person could travel back in time while in a black hole. The question is whether he could ever emerge to brag about it."

Another time machine involves a spinning universe. In 1949 mathematician Kurt Gödel found the first solution of Einstein's equations involving time travel. If the universe spins, then, if you traveled around the universe fast enough, you might find yourself in the past and arrive before you left. A trip around the universe is therefore also a trip into the past. When astronomers would visit the Institute for Advanced Study, Gödel would often ask them if they ever found evidence that the universe was spinning. He was disappointed when they told him that there was clearly evidence that the universe expanded, but the net spin of the universe was probably zero. (Otherwise, time travel might be commonplace, and history as we know it would collapse.)

Third, if you walk around an infinitely long, rotating cylinder, you also might arrive before you left. (This solution was found by W. J. van Stockum in 1936, before Gödel's time traveling solution, but van Stockum was apparently unaware that his solution allowed for time travel.) In this case, if you danced around a spinning May Pole on May Day, you might find yourself in the month of April. (The problem with this design, however, is that the cylinder must be infinite in length and spin so fast that most materials would fly apart.)

The most recent example of time travel was found by Richard Gott of Princeton in 1991. His solution was based on finding gigantic cosmic strings (which may be leftovers from the original big bang). He assumed that two large cosmic strings were about to collide. If you quickly traveled around these colliding cosmic strings, you would travel back in time. The advantage of this type of time machine is that you would not need infinite spinning cylinders, spinning universes, or black holes. (The problem with this design, however, is that you must first find huge cosmic strings floating in space and then make them collide in a precise fashion. And the possibility of going back in time would last only a brief period.) Gott says, "A collapsing loop of string large enough to allow you to circle it once and go back in time a year would have to have more than half the mass-energy of an entire galaxy."

But the most promising design for a time machine is the "transversable wormhole," mentioned in the last chapter, a hole in space-time in which a person could freely walk back and forth in time. On paper, transversable wormholes can provide not only faster-than-light travel, but also travel in time. The key to transversable wormholes is negative energy.

A transversable wormhole time machine would consist of two chambers. Each chamber would consist of two concentric spheres, which would be separated by a tiny distance. By imploding the outer sphere, the two spheres would create a Casimir effect and hence negative energy. Assume that a Type III civilization is able to string a wormhole between these two chambers (possibly extracting one from the space-time foam). Next, take the first chamber and send it into space at near light-speed velocities. Time slows down in that chamber, so the two clocks are no longer in synchronization. Time beats at different rates inside the two chambers, which are connected by a wormhole.

If you are in the second chamber, you can instantly pass through the wormhole to the first chamber, which exists at an earlier time. Thus you have gone backward in time.

There are formidable problems facing this design. The wormhole may be quite tiny, much smaller than an atom. And the plates may have to be squeezed down to Planck-length distances to create enough negative energy. Lastly, you would be able to go back in time only to the point when the time machines were built. Before then, time in the two chambers would be beating at the same rate.

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[14] Time travel and warp drives: a scientific guide to shortcuts through time and space,2012, Everett, Allen Roman, Thomas

Paradoxes And Time Conundrums:

Time travel poses all sorts of problems, both technical as well as social. The moral, legal, and ethical issues are raised by Larry Dwyer, who notes, "Should a time traveler who punches his younger self (or vice versa) be charged with assault? Should the time traveler who murders someone and then flees into the past for sanctuary be tried in the past for crimes he committed in the future? If he marries in the past can he be tried for bigamy even though his other wife will not be born for almost 5,000 years?"

But perhaps the thorniest problems are the logical paradoxes raised by time travel. For example, what happens if we kill our parents before we are born? This is a logical impossibility. It is sometimes called the "grandfather paradox."

There are three ways to resolve these paradoxes. First, perhaps you simply repeat past history when you go back in time, therefore fulfilling the past. In this case, you have no free will. You are forced to complete the past as it was written. Thus, if you go back into the past to give the secret of time travel to your younger self, then it was meant to happen that way. The secret of time travel came from the future. It was destiny. (But this does not tell us where the original idea came from.)

Second, you have free will, so you can change the past, but within limits. Your free will is not allowed to create a time paradox. Whenever you try to kill your parents before you are born, a mysterious force prevents you from pulling the trigger. This position has been advocated by the Russian physicist Igor Novikov. (He argues that there is a law preventing us from walking on the ceiling, although we might want to. Hence there might be a law preventing us from killing our parents before we are born. Some strange law prevents us from pulling the trigger.)

Third, the universe splits into two universes. On one time line the people whom you killed look just like your parents, but they are different, because you are now in a parallel universe. This latter possibility seems to be the one consistent with the quantum theory.

This means that all time travel paradoxes can be solved. If you have killed your parents before you were born, it simply means you have killed some people who are genetically identical to your parents, with the same memories and personalities, but they are not your true parents.

The "many worlds" idea solves at least one main problem with time travel. To a physicist, the number one criticism of time travel (besides finding negative energy) is that radiation effects will build up until either you are killed the instant you enter the machine or the wormhole collapses on you. Radiation effects build up because any radiation entering the time portal will be sent back into the past, where it will eventually wander around the universe until it reaches the present day, and then it will fall into the wormhole again. Since radiation can enter the mouth of the wormhole an infinite number of times, the radiation inside the wormhole can become incredibly strong enough to kill you. But the "many worlds" interpretation solves this problem. If the radiation goes into the time machine and is sent into the past, it then enters a new universe; it cannot reenter the time machine again, and again, and again. This simply means that there are an infinite number of universes, one for each cycle, and each cycle contains just one photon of radiation, not an infinite amount of radiation.

In 1997, the debate was clarified a bit when three physicists finally proved that Hawking's program to ban time travel was inherently flawed. Bernard Ray, Marek Radzikowski, and Robert Wald showed that time travel was consistent with all the known laws of physics, except in one place. When traveling in time, all the potential problems were concentrated at the event horizon (located near the entrance to the wormhole). But the horizon is precisely where we expect Einstein's theory to break down and quantum effects to take over. The problem is that whenever we try to calculate radiation effects as we enter a time machine, we have to use a theory that combines Einstein's theory of general relativity with the quantum theory of radiation. But whenever we naively try to marry these two theories, the resulting theory makes no sense: it yields a series of infinite answers that are meaningless.

This is where a theory of everything takes over. All problems of traveling through a wormhole that have bedeviled physicists (e.g., the stability of the wormhole, the radiation that might kill you, the closing of the wormhole as you entered it) are concentrated at the event horizon, precisely where Einstein's theory made no sense.

Thus the key to understanding time travel is to understand the physics of the event horizon, and only a theory of everything can explain this. This is the reason that most physicists today would agree that one way to definitively settle the time travel question is to come up with a complete theory of gravity and space-time.

A theory of everything would unite the four forces of the universe and enable us to calculate what would happen when we entered a time machine. Only a theory of everything could successfully calculate all the radiation effects created by a wormhole and definitively settle the question of how stable wormholes would be when we entered the time machine. And even then, we might have to wait for centuries or even longer to actually build a machine to test these theories.

Because the laws of time travel are so closely linked to the physics of wormholes, time travel seems to qualify as a Class II impossibility.

Class III impossibilities

5: Perpetual motion machines

Since recorded history, the holy grail for inventors, scientists, as well as charlatans and scam artists has been the fabled "perpetual motion machine," a device that runs forever without any loss of energy. An even better version is a device that can create *more* energy than it consumes, such as the Electron Pump, which creates free, limitless energy.

In the coming years, as our industrialized world gradually runs out of cheap oil, there will be enormous pressure to find abundant new sources of clean energy. Soaring gas prices, falling production, increased pollution, atmospheric changes-all are fueling a renewed, intense interest in energy.

Today a few inventors riding this wave of concern promise to deliver unlimited quantities of free energy, offering to sell their inventions for hundreds of millions. Scores of investors periodically line up, lured by sensational claims in the financial media that often hail these mavericks as the next Edison.

But if energy is so precious, then precisely what is the likelihood of our creating a perpetual motion machine? Are these devices truly impossible, or would their creation require a revision in the laws of physics?

History Viewed Through Energy

Energy is vital to civilization. In fact, all of human history can be viewed through the lens of energy. For 99.9 percent of human existence, primitive societies were nomadic, scratching a meager living scavenging and hunting for food. Life was brutal and short. The energy available to us was one-fifth of a horsepower-the power of our own muscles. Analyses of the bones of our ancestors show evidence of enormous wear and tear, caused by the crushing burdens of daily survival. Average life expectancy was less than twenty years.

But after the end of the last ice age about ten thousand years ago, we discovered agriculture and domesticated animals, especially the horse, gradually raising our energy output to one or two horsepower. This set into motion the first great revolution in human history. With the horse or ox, one man had enough energy to plow an entire field by himself, travel tens of miles in a day, or move hundreds of pounds of rock or grain from one place to another. For the first time in human history, families had a surplus of energy, and the result was the founding of our first cities. Excess energy meant that society could afford to support a class of artisans, architects, builders, and scribes, and thus ancient civilization could flourish. Soon great pyramids and empires rose from the jungles and desert. Average life expectancy reached about thirty years.

Then about three hundred years ago the second great revolution in human history took place. With the coming of machines and steam power, the energy available to a single person soared to tens of horsepower. By harnessing the power of the steam locomotive, people could now cross entire continents in a few days. Machines could plow entire fields, transport hundreds of passengers thousands of miles, and allow us to build huge towering cities. Average life expectancy by 1900 had reached almost fifty in the United States.

Today we are in the midst of the third great revolution in human history, the information revolution. Because of an exploding population and our ravenous appetite for electricity and power, our energy needs have skyrocketed and our energy supply is being stretched to the very limit. The energy available to a single individual is now measured in thousands of horsepower. We take for granted that a single car can generate hundreds of horsepower. Not surprisingly, this demand for more and more energy has sparked an interest in greater sources of energy, including perpetual motion machines.

Perpetual Motion Machines Through History

The search for a perpetual motion machine is an ancient one. The first recorded attempt to build a perpetual motion machine dates back to the eighth century in Bavaria. It was a prototype for hundreds of variations to come for the next thousand years; it was based on a series of small magnets attached to a wheel, like a Ferris wheel. The wheel was placed on top of a much larger magnet on the floor. As each magnet on the wheel passed over the stationary magnet, it was supposed to be attracted then repelled by the larger magnet, thereby pushing the wheel and creating perpetual motion.[15]

Another ingenious design was devised in 1150 by the Indian philosopher Bhaskara, who proposed a wheel that would run forever by adding a weight to the rim, causing the wheel to spin because it was unbalanced. Work would be done by the weight as it made a revolution, and then it would return to its original position. By iterating this over and over again, Bhaskara claimed that one could extract unlimited work for free.

The Bavarian and the Bhaskara designs for perpetual motion machines and their many descendants all share the same ingredients: a wheel of some sort that can make a single revolution without the addition of any energy, producing usable work in the process. (Careful examination of these ingenious machines usually shows that energy is actually lost in each cycle, or that no usable work can be extracted.)

The coming of the Renaissance accelerated proposals for a perpetual motion machine. In 1635 the first patent was granted for a perpetual motion machine. By 1712 Johann Bessler had analyzed some three hundred different models and proposed a design of his own. (According to legend, his maid later exposed his machine as a fraud.) Even the great renaissance painter and scientist Leonardo da Vinci became interested in perpetual motion machines. Although he denounced them in public, comparing them to the fruitless search for the philosopher's stone, in private he made ingenious sketches in his notebooks of self-propelling, perpetual motion machines, including a centrifugal pump and a chimney jack used to turn a roasting skewer over a fire.

By 1775 so many designs were being proposed that the Royal Academy of Science in Paris stated that it would "no longer accept or deal with proposals concerning perpetual motion."

Arthur Ord-Hume, a historian of these perpetual motion machines, has written about the tireless dedication of these inventors, working against incredible odds, comparing them to the ancient alchemists. But, he noted, "Even the alchemist... knew when he was beaten."

Hoaxes and Frauds

The incentive to produce a perpetual motion machine was so great that hoaxes became commonplace. In 1813 Charles Redheffer exhibited a machine in New York City that amazed audiences, producing unlimited energy for free. (But when Robert Fulton examined the machine carefully, he found a hidden cat-gut belt driving the machine. This cable was in turn connected to a man secretly turning a crank in the attic.)

In 1872 John Ernst Worrell Kelly perpetrated the most sensational and lucrative scam of his day, swindling investors of nearly $5 million, a princely sum back in the late nineteenth century. His perpetual motion machine was based on resonating tuning forks that he claimed tapped into the "ether." Kelly, a man with no scientific background, would invite wealthy investors to his house, where he would amaze them with his Hydro-Pneumatic-Pulsating-Vacuo-Engine, which whizzed around without any external power source. Eager investors, amazed by this self-propelled machine, flocked to pour money into his coffers.

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[15] Perpetual Motion Machine: The Story of an Invention,2011, Scheerbart, Paul Joron, Andrew

Later some disillusioned investors angrily accused him of fraud, and he actually spent some time in jail, although he died a wealthy man. After his death investigators found the clever secret of his machine. When his house was torn down concealed tubes were found in the floor and walls of the basement that secretly delivered compressed air to his machines. These tubes in turn were energized by a flywheel.

Even the U.S. Navy and the president of the United States were taken in by such a machine. In 1881 John Gamgee invented a liquid ammonia machine. The vaporization of cold ammonia would create expanding gases that could move a piston, and hence could power machines using only the heat of the oceans themselves. The U.S. Navy was so enthralled with the idea of extracting unlimited energy from the oceans that it approved the device and even demonstrated it to President James Garfield. The problem was that the vapor did not condense back into a liquid properly; hence the cycle could not be completed.

So many proposals for perpetual motion machines have been presented to the U.S. Patent and Trademark Office (USPTO) that the office refuses to grant a patent for such a device unless a working model is presented. In certain rare circumstances, when the patent examiners can find nothing obviously wrong with a model, a patent is granted. The USPTO states, "With the exception of cases involving perpetual motion, a model is not ordinarily required by the Office to demonstrate the operability of a device." (This loophole has allowed unscrupulous inventors to persuade naïve investors to finance their inventions by claiming that the USPTO has officially recognized their machine.)

The pursuit of the perpetual motion machine, however, has not been fruitless from a scientific point of view. On the contrary, although inventors have never produced a perpetual motion machine, the enormous time and energy invested in building such a fabled machine has led physicists to carefully study the nature of heat engines. (In the same way, the fruitless search of alchemists for the philosopher's stone, which can turn lead into gold, helped to uncover some of the basic laws of chemistry.)

For example, in the 1760s John Cox developed a clock that could actually run forever, powered by changes in atmospheric pressure. Changes in air pressure would drive a barometer, which would then turn the hands of the clock. This clock actually worked and exists even today. The clock can run forever because energy is extracted from the outside in the form of changes in atmospheric pressure.

Perpetual motion machines like Cox's eventually led scientists to hypothesize that such machines could run forever only if energy was brought in to the device from the outside, that is, that total energy was conserved. This theory eventually led to the First Law of Thermodynamics-

that the total amount of matter and energy cannot be created or destroyed. Eventually three laws of thermodynamics were postulated. The Second Law states that the total amount of entropy (disorder) always increases. (Crudely speaking, this law says that heat flows spontaneously only from hotter to colder places.) The Third Law states that you can never reach absolute zero.

If we compare the universe to a game and the goal of this game is to extract energy, then the three laws can be rephrased as follows:

"You can't get something for nothing." (First Law)
"You can't break even." (Second Law)
"You can't even get out of the game." (Third Law)

(Physicists are careful to state that these laws are not necessarily absolutely true for all time. Nevertheless, no deviation has ever been found. Anyone trying to disprove these laws must go against centuries of careful scientific experiments. We will discuss possible deviations from these laws shortly.)

These laws, among the crowning achievements of nineteenth century science, are marked by tragedy as well as triumph. One of the key figures in formulating these laws, the great German physicist Ludwig Boltzmann, committed suicide, in part because of the controversy he created in formulating these laws.

Ludwig Boltzmann and Entropy

Boltzmann was a short, barrel-chested bear of a man, with a huge, forest like beard. His formidable and ferocious appearance, however, belied all the wounds he suffered in defending his ideas. Although Newtonian physics was firmly established by the nineteenth century, Boltzmann knew these laws had never been rigorously applied to the controversial concept of atoms, a concept that was still not accepted by many leading scientists. (We sometimes forget that as late as a century ago there were legions of scientists who insisted that the atom was just a clever gimmick, not a real entity. Atoms were so impossibly tiny, they claimed, that they probably didn't exist at all).

Newton showed that mechanical forces, not spirits or desires, were sufficient to determine the motion of all objects. Boltzmann then elegantly derived many of the laws of gases by a simple assumption: that gases were made of tiny atoms that, like billiard balls, obeyed the laws of forces laid down by Newton. To Boltzmann, a chamber containing gas was like a box filled with trillions of tiny steel balls, each one bouncing off the walls and each other according to Newton's laws of motion. In one of the greatest masterpieces in physics, Boltzmann (and independently James Clerk Maxwell) mathematically showed how this simple assumption could result in dazzling new laws and open up a new branch of physics called statistical mechanics.

Suddenly many of the properties of matter could be derived from first principles. Since Newton's laws stipulated that energy must be conserved when applied to atoms, each collision between atoms conserved energy; that meant that an entire chamber of trillions of atoms also conserved energy. The conservation of energy could now be established not just via experimentation, but from first principles, that is, the Newtonian motion of atoms.

But in the nineteenth century the existence of atoms was still hotly debated and often ridiculed by prominent scientists, such as philosopher Ernst Mach. A sensitive and often depressed man, Boltzmann uncomfortably found himself the lightning rod, the focus of the often vicious attacks by the anti-atomists. To the anti-atomists, anything that could not be measured did not exist, including atoms. To add to Boltzmann's humiliation, many of his papers were rejected by the editor of a prominent German physics journal because the editor insisted that atoms and molecules were strictly convenient theoretical tools, rather than objects that really existed in nature.

Exhausted and embittered from all the personal attacks, Boltzmann hung himself in 1906 while his wife and child were at the beach. Sadly, he did not realize that just a year before, a brash young physicist by the name of Albert Einstein had done the impossible: he had written the first paper demonstrating the existence of atoms.

Total Entropy Always Increases

The work of Boltzmann and other physicists helped to clarify the nature of perpetual motion machines, sorting them into two types. Perpetual motion machines of the first type are those that violate the First Law of Thermodynamics; that is, they actually produce more energy than they consume. In every case physicists found that this type of perpetual motion machine relied on hidden, outside sources of energy, either through fraud, or because the inventor did not realize the source of the outside energy.

Perpetual motion machines of the second type are subtler. They obey the First Law of Thermodynamics-conserving energy-but violate the Second Law. In theory, a perpetual motion machine of the second type produces no waste heat, so it is 100 percent efficient. Yet the Second Law says that such a machine is impossible-that waste heat must always be produced-and hence disorder or chaos in the universe, or entropy, always increases. No matter how efficient a machine might be, it will always produce some waste heat, thereby raising the entropy of the universe.

The fact that total entropy always increases lies at the heart of human history as well as mother nature. According to the Second Law, it is far easier to destroy than to build. Something that might take thousands of years to create, such as the great Aztec Empire in Mexico, can be destroyed in a matter of months; and this is what happened when a raggedy band of Spanish conquistadores, armed with horses and firearms, completely shattered that empire.

Every time you look in a mirror and see a new wrinkle or a white hair you are observing the effects of the Second Law. Biologists tell us that the aging process is the gradual accumulation of genetic errors in our cells and genes, so that the cell's ability to function slowly deteriorates. Aging, rusting, rotting, decay, disintegration, and collapse are also examples of the Second Law.

Remarking on the profound nature of the Second Law, astronomer Arthur Eddington once said, "The law that entropy always increases holds, I think, the supreme position among the laws of Nature... if your theory is found to be against the second law of thermodynamics, I can give you no hope; there is nothing for it but to collapse in deepest humiliation."

Even today enterprising engineers (and clever charlatans) continue to announce the invention of perpetual motion machines. Recently physicist Michio Kaku was asked by the *Wall Street Journal* to comment on the work of an inventor who had actually persuaded investors to sink millions of dollars into his machine. Breathless articles were published in major financial newspapers, written by journalists with no background in science, gushing about the potential of this invention to change the world (and generate fabulous, lucrative profits in the process). "Genius or crackpot?" the headlines blared.

Investors threw enormous bundles of cash at this device, which violated the most basic laws of physics and chemistry taught in high school.

The Three Laws And Symmetries

But all this raises a deeper question: Why do the iron laws of thermodynamics hold in the first place? It is a mystery that has intrigued scientists since the laws were first proposed. If we could answer that question, perhaps we might find loopholes in the laws, and the implications would be earth-shattering.

The true origin of the conservation of energy. One of the fundamental principles of physics (discovered by mathematician Emmy Noether in 1918) is that whenever a system possesses symmetry, the result is a conservation law. If the laws of the universe remain the same over time, then the astonishing result is that the system conserves energy. (Furthermore, if the laws of physics remain the same if you move in any direction, then momentum is conserved in any direction as well. And if the laws of physics remain the same under a rotation, then angular momentum is conserved.)

I realized that when we analyze starlight from distant galaxies that are billions of light-years away, at the very edge of the visible universe, we find that the spectrum of light is identical to spectra that we can find on Earth. In the relic light that was emitted billions of years before Earth or the sun was born, we see the same unmistakable "fingerprints" of the spectrum of hydrogen, helium, carbon, neon, and so forth, that we find on the Earth today. In other words, the basic laws of physics haven't changed for billions of years, and they are constant out to the outer edges of the universe.

At a minimum, Noether's theorem means that the conservation of energy will probably last for billions of years, if not forever. As far as we know, none of the fundamental laws of physics have changed with time, and this is the reason that energy is conserved.

The implications of Noether's theorem on modern physics are profound. Whenever physicists create a new theory, whether it addresses the origin of the universe, the interactions of quarks and other subatomic particles, or antimatter, we first start with the symmetries that the system obeys. In fact, symmetries are now known to be the fundamental guiding principle in creating any new theory. In the past, symmetries were thought to be by-products of a theory-a cute but ultimately useless feature of a theory, pretty, but not essential. Today we realize that symmetries are the essential feature that defines any theory. In creating new theories, physicists first start with symmetry, and then build the theory around it.

This raises a disturbing question. If energy is conserved because the laws of physics do not change with time, then could this symmetry be broken in rare, unusual circumstances? There is still the possibility that the conservation of energy might be violated on a cosmic scale, if the symmetry of our laws is broken in exotic and unexpected places.

Energy from the Vacuum??

A tantalizing question is: Is it possible to extract energy from nothing? Physicists have only recently realized that the "nothing" of the vacuum is not empty at all, but teaming with activity.

One of the proponents of this idea was the eccentric genius of the twentieth century Nikola Tesla, a worthy rival to Thomas Edison. He was also one of the proponents of zero-point energy, that is, the idea that the vacuum may possess untold quantities of energy. If true, the vacuum would be the ultimate "free lunch," capable of providing unlimited energy literally from thin air. The vacuum, instead of being considered empty and devoid of any matter, would be the ultimate storehouse of energy.

Tesla's inventions and patents number over seven hundred and contain some of the most important milestones in modern electrical history. Historians have made a credible case that Tesla invented radio before Guglielmo Marconi (widely recognized as the inventor of radio) and was working with X-rays before their official discovery by Wilhelm Roentgen.

Tesla also believed that he could extract unlimited energy from the vacuum, a claim that unfortunately he did not prove in his notes. At first, "zero-point energy" (or the energy contained in a vacuum) seems to violate the First Law of Thermodynamics. Although zero-point energy defies the laws of Newtonian mechanics, the notion of zero-point energy has reemerged recently from a novel direction.

When scientists analyze the data from satellites currently orbiting the Earth, such as the WMAP satellite, they have come to the astounding conclusion that fully 73 percent of the universe is made of "dark energy," the energy of a pure vacuum. This means that the greatest reservoir of energy in the entire universe is the vacuum that separates the galaxies in the universe. (This dark energy is so colossal that it is pushing the galaxies away from each other, and may eventually rip the universe apart in a Big Freeze.)

Dark energy is everywhere in the universe, even in your living room and inside your body. The amount of dark energy in outer space is truly astronomical, outweighing all the energy of the stars and galaxies put together. We can also calculate the amount of dark energy on the Earth, and it is quite small, too small to be used to power a perpetual motion machine. Tesla was right about dark energy but wrong about the amount of dark energy on the Earth. Or was he?

One of the most embarrassing gaps in modern physics is that no one can calculate the amount of dark energy that we can measure via our satellites. If we use the latest theory of atomic physics to calculate the amount of dark energy in the universe, we arrive at a number that is wrong by a factor of 10120! That is "one" followed by 120 zeros! This is by far the largest mismatch between theory and experiment in all of physics.

The point is that no one knows how to calculate the "energy of nothing." This is one of the most important questions in physics (because it will eventually determine the fate of the universe), but at the present time we are clueless as to how to calculate it. No theory can explain dark energy, although experimental evidence for its existence is staring us in the face.

So the vacuum does have energy, as Tesla suspected. But the amount of energy is probably too small to be used as a source of usable energy. There are vast amounts of dark energy between the galaxies, but the amount that can be found on the Earth is tiny. But the embarrassing thing is that no one knows how to calculate this energy, or where it came from.

My point is that the conservation of energy arises from deep, cosmological reasons. Any violation of these laws would necessarily mean a profound shift in our understanding of the evolution of the universe. And the mystery of dark energy is forcing physicists to confront this question head-on.

Because creating a true perpetual motion machine may require us to reevaluate the fundamental laws of physics on a cosmological scale, I would rank perpetual motion machines as a Class III impossibility; that is, either they are truly impossible, or we would need to fundamentally change our understanding of fundamental physics on a cosmological scale in order to make such a machine possible. Dark energy remains one of the great unfinished chapters in modern science.

Epilogue

The Future of the Impossible

If we could go back to the year 1900 to visit our grandparents, how would they view us? Back then, life expectancy hovered around 40, people were largely dirt farmers and life was short and brutal. Viewing our rockets, jet airplanes, TVs, computers, and Internet, they would see us as sorcerers and wizards.

But if someone from 2100 could visit us now, how would we view them? Probably like the gods of mythology. They would command everything around them by wishing for it. They would have perfect and ageless bodies. And they would ride across the universe in magical chariots. In the past, we feared the gods of mythology. In the next 100 years, will we become them?

A day in 2300?

1- The Internet will be in your contact lens. Imagine blinking, and then instantly going on line, accessing your home office, or home entertainment system anywhere or anytime. We will be able to download any movie, song, Web site, or piece of information off the Internet directly onto our Internet-enabled contact lenses. These lenses will also be able to identify people's faces, translate their comments and provide subtitles, so that we will always know exactly with whom we are speaking and what they are saying in any language. We will live in a cross between "The Matrix" and real life. Tourists will love this, for example, since they will be able to see the glory of the Roman Empire resurrected in their contact lens as they walk among the ruins of Rome. Artists and architects will love it, as well, since they will be able to create great works of art by simply moving their hands in the air. People suffering from illnesses, like diabetes, will love it, too, because they will have immediate readouts of their heart rate, insulin levels, and other important conditions within their own bodies.

2- Computers will disappear, as will cellphones, clocks, watches, and MP3 players. Chips, costing less than a penny apiece, will be hidden by the millions in the environment. We will be able to command these hidden computers telepathically, directly via the mind. Computers will interpret the electrical signals emitted by our brains, decipher them, and carry out our wishes. When we walk into a room, we will be able to mentally control a computer that in turn will direct the many things around us. Moving heavy furniture, rearranging desks, and brewing a cup of coffee may be possible just by thinking about it. So we will be like the gods of mythology, mentally manipulating the world around us. We will also be able to conjure up almost any object just by wishing for it. This is done via "programmable matter," which consists of millions of microscopic computer chips, which are intelligent and can be programmed to suddenly rearrange themselves into any shape or object on command, so that we will be able to create almost anything we can imagine.

3- Our cars will be driver-less, using GPS to navigate without the help of an alert human behind the wheel. These cars will also fly by floating on a cushion of magnetism. With room-temperature superconducting magnets, our cars and trains will glide effortlessly in the air without bumps or potholes to worry about since the crafts hover over the treacherous road. Traffic jams and accidents will be a thing of the past as a central computer will be able to track the motions of all the cars on the road, while each car will use radar in its fenders to sense obstacles and take emergency measures as soon as it senses an impending accident. Best of all, we will hardly ever need to fuel up, since there is almost no friction to slow us down. This will also solve the energy crisis, since most energy is wasted, strangely enough, on overcoming the friction of the road.

4- The robot industry will dwarf the size of the current automobile industry. Robots will be everywhere, performing dangerous and tedious tasks. They will have emotions. They will be friendly, polite, helpful (and with fail-safe devices to prevent accidents). Many robots won't exist in human form, but will be hidden from view, the size of snakes, insects and spiders, and undertaking various unpleasant and dangerous tasks in place of humans. They will also be used as cooks, surgeons, musicians, pets, store clerks and so forth. By the end of the century, robots will be nearly as smart as humans and may replace many jobs. Among the worse off will be blue-collar workers who perform repetitive jobs that are easily replaced by robots. However, there are a large number of blue-collar jobs that will survive, including garbage collectors, police officers, gardeners and plumbers, who are all dependent on pattern recognition. Among white-collar workers, the losers will be those involved taking inventory and "bean counting," such as low-level agents, brokers, tellers, and accountants. However, novelists, scriptwriters, artists, entertainers, and jobs that deal in human relations, such as lawyers, will persist.

5- Tourists will soar into outer space via the Space Elevator. We will push the "up" button and the elevator will climb up a long carbon fiber cable, which extends thousands of miles into space. This will open up the solar system to wealthy tourists and the outer- space-obsessed. The key is to use nanotechnology to create these super-strong cables made of carbon. In addition, scientists will be preparing the first starship capable of leaving the solar system and visiting the nearest stars. New propulsion systems, perhaps involving antimatter or fusion engines, will take us there. By the end of the century, we may have a small outpost on Mars, but an overwhelming fraction of the human race will still be on earth. For decades to centuries to come, space travel will be for astronauts, the wealthy and maybe a handful of hardy space colonists.

6- Because cheap oil will eventually run out and because burning fossil fuels drives global warming, new forms of energy are desperately needed. Within a decade, solar/wind/renewable technologies will drop in price and be competitive with oil, due to the rising cost of fossil fuels. fusion power becomes a major player. That is when the International Thermonuclear Experimental Reactor (ITER) becomes operational in southern France. Costing over $10 billion dollars, it is a crash project designed from the start to generate more energy than it consumes.

Rather than burning uranium (which creates vast amounts of nuclear waste and the danger of meltdowns) fusion reactors cleanly burn hydrogen, which is found in sea water. Fusion is the energy source which powers the sun, the stars, and the universe. A decade after that, commercial fusion power plants may proliferate around the world, thereby solving the energy crisis and global warming. Clean, safe, and renewable, fusion power promises to energize our economy.

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