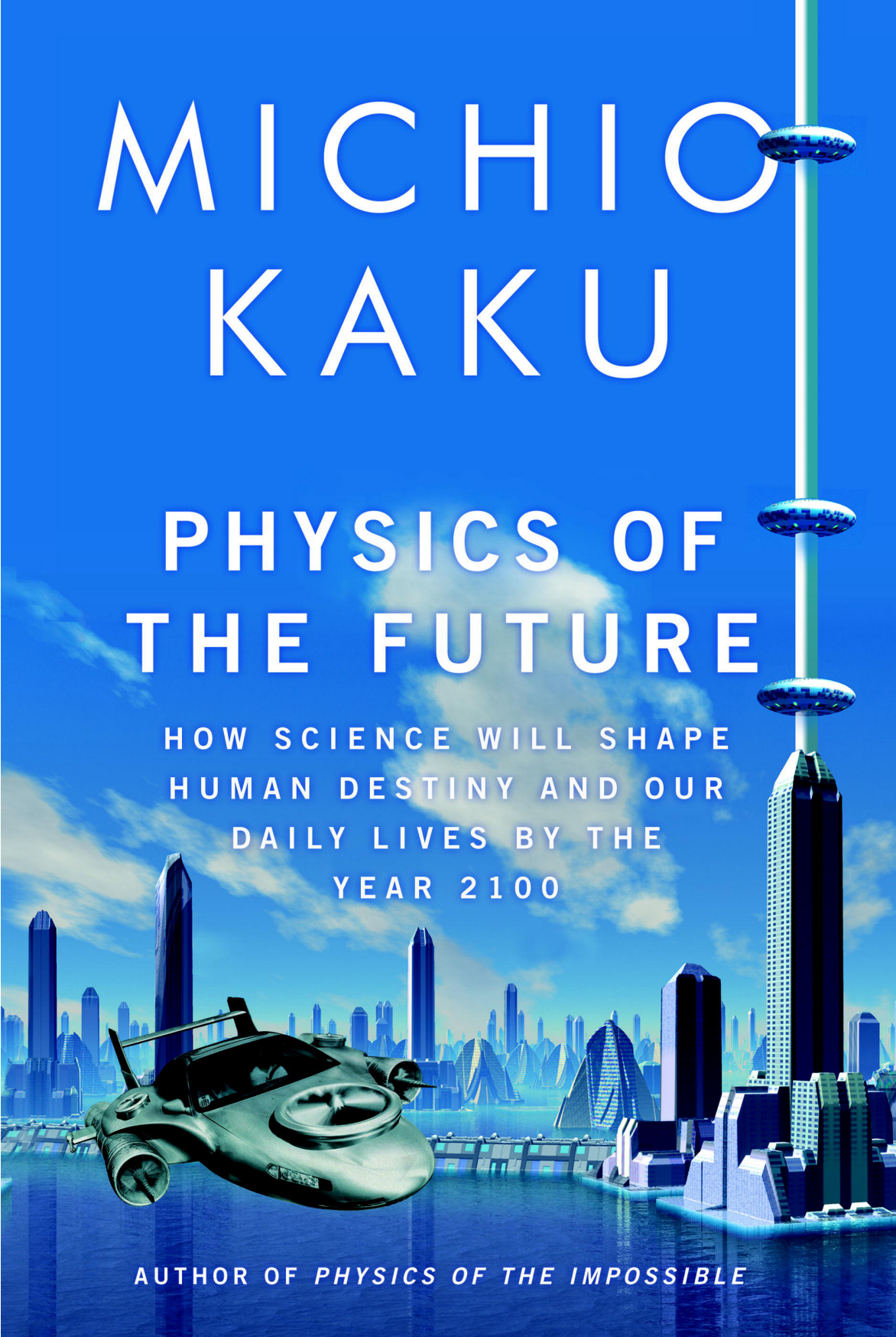
MICHIO KAKU

PHYSICS OF THE FUTURE

HOW SCIENCE WILL SHAPE HUMAN DESTINY AND OUR DAILY LIVES BY THE YEAR 2100



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Empires of the future will be empires of the mind.

—WINSTON CHURCHILL

INTRODUCTION *Predicting the Next 100 Years*

When I was a child, two experiences helped to shape the person I am today and spawned two passions that have helped to define my entire life.

First, when I was eight years old, I remember all the teachers buzzing with the latest news that a great scientist had just died. That night, the newspapers printed a picture of his office, with an unfinished manuscript on his desk. The caption read that the greatest scientist of our era could not finish his greatest masterpiece. What, I asked myself, could be so difficult that such a great scientist could not finish it? What could possibly be that complicated and that important? To me, eventually this became more fascinating than any murder mystery, more intriguing than any adventure story. I had to know what was in that unfinished manuscript.

Later, I found out that the name of this scientist was Albert Einstein and the unfinished manuscript was to be his crowning achievement, his attempt to create a "theory

of everything," an equation, perhaps no more than one inch wide, that would unlock the secrets of the universe and perhaps allow him to "read the mind of God."

But the other pivotal experience from my childhood was when I watched the Saturday morning TV shows, especially the *Flash Gordon* series with Buster Crabbe. Every week, my nose was glued to the TV screen. I was magically transported to a mysterious world of space aliens, starships, ray gun battles, underwater cities, and monsters. I was hooked. This was my first exposure to the world of the future. Ever since, I've felt a childlike wonder when pondering the future.

But after watching every episode of the series, I began to realize that although Flash got all the accolades, it was the scientist Dr. Zarkov who actually made the series work. He invented the rocket ship, the invisibility shield, the power source for the city in the sky, etc. Without the scientist, there is no future. The handsome and the beautiful may earn the admiration of society, but all the wondrous inventions of the future are a by-product of the unsung, anonymous scientists.

Later, when I was in high school, I decided to follow in the footsteps of these great scientists and put some of my learning to the test. I wanted to be part of this great revolution that I knew would change the world. I decided to build an atom smasher. I asked my mother for permission to build a 2.3-million electron volt particle accelerator in the garage. She was a bit startled but gave me the okay. Then, I went to Westinghouse and Varian Associates, got 400 pounds of transformer steel, 22 miles of copper wire, and assembled a betatron accelerator in my mom's garage.

Previously, I had built a cloud chamber with a powerful magnetic field and photographed tracks of antimatter. But photographing antimatter was not enough. My goal now was to produce a beam of antimatter. The atom smasher's magnetic coils successfully produced a huge 10,000 gauss magnetic field (about 20,000 times the earth's magnetic field, which would in principle be enough to rip a hammer right out of your hand). The machine soaked up 6 kilowatts of power, draining all the electricity my house could provide. When I turned on the machine, I frequently blew out all the fuses in the house. (My poor mother must have wondered why she could not have a son who played football instead.)

So two passions have intrigued me my entire life: the desire to under-

stand all the physical laws of the universe in a single coherent theory and the desire to see the future. Eventually, I realized that these two passions were actually complementary. The key to understanding the future is to grasp the fundamental laws of nature and then apply them to the inventions, machines, and therapies that will redefine our civilization far into the future.

There have been, I found out, numerous attempts to predict the future, many useful and insightful. However, they were mainly written by historians, sociologists, science fiction writers, and "futurists," that is, outsiders who are predicting the world of science without a firsthand knowledge of the science itself. The scientists, the insiders who are actually creating the future in their laboratories, are too busy making breakthroughs to have time to write books about the future for the public.

That is why this book is different. I hope this book will give an insider's perspective on what miraculous discoveries await us and provide the most authentic, authoritative look into the world of 2100.

Of course, it is impossible to predict the future with complete accuracy. The best one can do, I feel, is to tap into the minds of the scientists at the cutting edge of research, who are doing the yeoman's work of inventing the future. They are the ones who are creating the devices, inventions, and therapies that will revolutionize civilization. And this book is their story. I have had the opportunity to sit in the front-row seat of this great revolution, having interviewed more than 300 of the world's top scientists, thinkers, and dreamers for national TV and radio. I have also taken TV crews into their laboratories to film the prototypes of the remarkable devices that will change our future. It has been a rare honor to have hosted numerous science specials for BBC-TV, the Discovery Channel, and the Science Channel, profiling the remarkable inventions and discoveries of the visionaries who are daring to create the future. Being free to pursue my work on string theory and to eavesdrop on the cutting-edge research that will revolutionize this century, I feel I have one of the most desirable jobs in science. It is my childhood dream come true.

But this book differs from my previous ones. In books like *Beyond Einstein, Hyperspace,* and *Parallel Worlds,* I discussed the fresh, revolutionary winds sweeping through my field, theoretical physics, that are opening up new ways to understand the universe. In *Physics of the Impossible,* I dis-

cussed how the latest discoveries in physics may eventually make possible even the most imaginative schemes of science fiction.

This book most closely resembles my book *Visions,* in which I discussed how science will evolve in the coming decades. I am gratified that many of the predictions made in that book are being realized today on schedule. The accuracy of my book, to a large degree, has depended on the wisdom and foresight of the many scientists I interviewed for it.

But this book takes a much more expansive view of the future, discussing the technologies that may mature in 100 years, that will ultimately determine the fate of humanity. How we negotiate the challenges and opportunities of the next 100 years will determine the ultimate trajectory of the human race.

PREDICTING THE NEXT CENTURY

Predicting the next few years, let alone a century into the future, is a daunting task. Yet it is one that challenges us to dream about technologies we believe will one day alter the fate of humanity.

In 1863, the great novelist Jules Verne undertook perhaps his most ambitious project. He wrote a prophetic novel, called *Paris in the Twentieth Century,* in which he applied the full power of his enormous talents to forecast the coming century. Unfortunately, the manuscript was lost in the mist of time, until his great-grandson accidentally stumbled upon it lying in a safe where it had been carefully locked away for almost 130 years. Realizing what a treasure he had found, he arranged to have it published in 1994, and it became a best seller.

Back in 1863, kings and emperors still ruled ancient empires, with impoverished peasants performing backbreaking work toiling in the fields. The United States was consumed by a ruinous civil war that would almost tear the country apart, and steam power was just beginning to revolutionize the world. But Verne predicted that Paris in 1960 would have glass skyscrapers, air conditioning, TV, elevators, high-speed trains, gasoline-powered automobiles, fax machines, and even something resembling the Internet. With uncanny accuracy, Verne depicted life in modern Paris.

This was not a fluke, because just a few years later he made another spectacular prediction. In 1865, he wrote *From the Earth to the Moon,* in

which he predicted the details of the mission that sent our astronauts to the moon more than 100 years later in 1969. He accurately predicted the size of the space capsule to within a few percent, the location of the launch site in Florida not far from Cape Canaveral, the number of astronauts on the mission, the length of time the voyage would last, the weightlessness that the astronauts would experience, and the final splashdown in the ocean. (The only major mistake was that he used gunpowder, rather than rocket fuel, to take his astronauts to the moon. But liquid-fueled rockets wouldn't be invented for another seventy years.)

How was Jules Verne able to predict 100 years into the future with such breathtaking accuracy? His biographers have noted that, although Verne was not a scientist himself, he constantly sought out scientists, peppering them with questions about their visions of the future. He amassed a vast archive summarizing the great scientific discoveries of his time. Verne, more than others, realized that science was the engine shaking the foundations of civilization, propelling it into a new century with unexpected marvels and miracles. The key to Verne's vision and profound insights was his grasp of the power of science to revolutionize society.

Another great prophet of technology was Leonardo da Vinci, painter, thinker, and visionary. In the late 1400s, he drew beautiful, accurate diagrams of machines that would one day fill the skies: sketches of parachutes, helicopters, hang gliders, and even airplanes. Remarkably, many of his inventions would have flown. (His flying machines, however, needed one more ingredient: at least a 1-horsepower motor, something that would not be available for another 400 years.)

What is equally astonishing is that Leonardo sketched the blueprint for a mechanical adding machine, which was perhaps 150 years ahead of its time. In 1967, a misplaced manuscript was reanalyzed, revealing his idea for an adding machine with thirteen digital wheels. If one turned a crank, the gears inside turned in sequence performing the arithmetic calculations. (The machine was built in 1968 and it worked.)

In addition, in the 1950s another manuscript was uncovered which contained a sketch for a warrior automaton, wearing German-Italian armor, that could sit up and move its arms, neck, and jaw. It, too, was subsequently built and found to work.

Like Jules Verne, Leonardo was able to get profound insights into the

future by consulting a handful of forward-thinking individuals of his time. He was part of a small circle of people who were at the forefront of innovation. In addition, Leonardo was always experimenting, building, and sketching models, a key attribute of anyone who wants to translate thinking into reality.

Given the enormous, prophetic insights of Verne and Leonardo da Vinci, we ask the question: Is it possible to predict the world of 2100? In the tradition of Verne and Leonardo, this book will closely examine the work of the leading scientists who are building prototypes of the technologies that will change our future. This book is not a work of fiction, a by-product of the overheated imagination of a Hollywood scriptwriter, but rather is based on the solid science being conducted in major laboratories around the world today.

The prototypes of all these technologies already exist. As William Gibson, the author of *Neuromancer* who coined the word *cyberspace,* once said, "The future is already here. It's just unevenly distributed."

Predicting the world of 2100 is a daunting task, since we are in an era of profound scientific upheaval, in which the pace of discovery is always accelerating. More scientific knowledge has been accumulated just in the last few decades than in all human history. And by 2100, this scientific knowledge will again have doubled many times over.

But perhaps the best way to grasp the enormity of predicting 100 years into the future is to recall the world of 1900 and remember the lives our grandparents lived.

Journalist Mark Sullivan asks us to imagine someone reading a newspaper in the year 1900:

> In his newspapers of January 1, 1900, the American found no such word as radio, for that was yet twenty years in from coming; nor "movie," for that too was still mainly of the future; nor chauffeur, for the automobile was only just emerging and had been called "horseless carriage. . . ." There was no such word as aviator. . . . Farmers had not heard of tractors, nor bankers of the Federal Reserve System. Merchants had not heard of chain-stores nor "self-service"; nor seamen of oil-burning engines. . . . Ox-teams could still be seen on country roads. . . . Horses or mules for trucks were practically

universal. . . . The blacksmith beneath the spreading chestnut-tree was a reality.

To understand the difficulty of predicting the next 100 years, we have to appreciate the difficulty that the people of 1900 had in predicting the world of 2000. In 1893, as part of the World's Columbian Exposition in Chicago, seventy-four well-known individuals were asked to predict what life would be like in the next 100 years. The one problem was that they consistently underestimated the rate of progress of science. For example, many correctly predicted that we would one day have commercial transatlantic airships, but they thought that they would be balloons. Senator John J. Ingalls said, "It will be as common for the citizen to call for his dirigible balloon as it now is for his buggy or his boots." They also consistently missed the coming of the automobile. Postmaster General John Wanamaker stated that the U.S. mail would be delivered by stagecoach and horseback, even 100 years into the future.

This underestimation of science and innovation even extended to the patent office. In 1899, Charles H. Duell, commissioner of the U.S. Office of Patents, said, "Everything that can be invented has been invented."

Sometimes experts in their own field underestimated what was happening right beneath their noses. In 1927, Harry M. Warner, one of the founders of Warner Brothers, remarked during the era of silent movies, "Who the hell wants to hear actors talk?"

And Thomas Watson, chairman of IBM, said in 1943, "I think there is a world market for maybe five computers."

This underestimation of the power of scientific discovery even extended to the venerable *New York Times.* (In 1903, the *Times* declared that flying machines were a waste of time, just a week before the Wright brothers successfully flew their airplane at Kitty Hawk, North Carolina. In 1920, the *Times* criticized rocket scientist Robert Goddard, declaring his work nonsense because rockets cannot move in a vacuum. Forty-nine years later, when *Apollo 11* astronauts landed on the moon, the *Times,* to its credit, ran the retraction: "It is now definitely established that a rocket can function in a vacuum. The *Times* regrets the error.")

The lesson here is that it is very dangerous to bet against the future.

Predictions for the future, with a few exceptions, have always under-

estimated the pace of technological progress. History, we are told over and over again, is written by the optimists, not the pessimists. As President Dwight Eisenhower once said, "Pessimism never won a war."

We can even see how science fiction writers underestimated the pace of scientific discovery. When watching reruns of the old 1960s TV series *Star Trek,* you notice that much of this "twenty-third-century technology" is already here. Back then, TV audiences were startled to see mobile phones, portable computers, machines that could talk, and typewriters that could take dictation. Yet all these technologies exist today. Soon, we will also have versions of the universal translator, which can rapidly translate between languages as you speak, and also "tricorders," which can diagnose disease from a distance. (Excepting warp drive engines and transporters, much of this twenty-third-century science is already here.)

Given the glaring mistakes people have made in underestimating the future, how can we begin to provide a firmer scientific basis to our predictions?

UNDERSTANDING THE LAWS OF NATURE

Today, we are no longer living in the dark ages of science, when lightning bolts and plagues were thought to be the work of the gods. We have a great advantage that Verne and Leonardo da Vinci did not have: a solid understanding of the laws of nature.

Predictions will always be flawed, but one way to make them as authoritative as possible is to grasp the four fundamental forces in nature that drive the entire universe. Each time one of them was understood and described, it changed human history.

The first force to be explained was the force of gravity. Isaac Newton gave us a mechanics that could explain that objects moved via forces, rather than mystical spirits and metaphysics. This helped to pave the way for the Industrial Revolution and the introduction of steam power, especially the locomotive.

The second force to be understood was the electromagnetic force, which lights up our cities and powers our appliances. When Thomas Edison, Michael Faraday, James Clerk Maxwell, and others helped to explain electricity and magnetism, this unleashed the electronic revolution that has created a bounty of scientific wonders. We see this every time there is a

power blackout, when society is suddenly wrenched back 100 years into the past.

The third and fourth forces to be understood were the two nuclear forces: the weak and strong forces. When Einstein wrote down $E = mc^2$ and when the atom was split in the 1930s, scientists for the first time began to understand the forces that light up the heavens. This revealed the secret behind the stars. Not only did this unleash the awesome power of atomic weapons, it also held out the promise that one day we would be able to harness this power on the earth.

Today, we have a fairly good grasp of these four forces. The first force, gravity, is now described through Einstein's theory of general relativity. And the other three forces are described through the quantum theory, which allows us to decode the secrets of the subatomic world.

The quantum theory, in turn, has given us the transistor, the laser, and the digital revolution that is the driving force behind modern society. Similarly, scientists were able to use the quantum theory to unlock the secret of the DNA molecule. The blinding speed of the biotechnological revolution is a direct result of computer technology, since DNA sequencing is all done by machines, robots, and computers.

As a consequence, we are better able to see the direction that science and technology will take in the coming century. There will always be totally unexpected, novel surprises that leave us speechless, but the foundation of modern physics, chemistry, and biology has largely been laid, and we do not expect any major revision of this basic knowledge, at least in the foreseeable future. As a result, the predictions we make in this book are the product not of wild speculation but are reasoned estimates of when the prototype technologies of today will finally reach maturity.

In conclusion, there are several reasons to believe that we can view the outlines of the world of 2100:

1. This book is based on interviews with more than 300 top scientists, those in the forefront of discovery.
2. Every scientific development mentioned in this book is consistent with the known laws of physics.
3. The four forces and the fundamental laws of nature are largely known; we do not expect any major new changes in these laws.
4. Prototypes of all technologies mentioned in this book already exist.

5. This book is written by an "insider" who has a firsthand look at the technologies that are on the cutting edge of research.

For countless eons we were passive observers of the dance of nature. We only gazed in wonder and fear at comets, lightning bolts, volcanic eruptions, and plagues, assuming that they were beyond our comprehension. To the ancients, the forces of nature were an eternal mystery to be feared and worshipped, so they created the gods of mythology to make sense of the world around them. The ancients hoped that by praying to these gods they would show mercy and grant them their dearest wishes.

Today, we have become choreographers of the dance of nature, able to tweak the laws of nature here and there. But by 2100, we will make the transition to being masters of nature.

2100: BECOMING THE GODS OF MYTHOLOGY

Today, if we could somehow visit our ancient ancestors and show them the bounty of modern science and technology, we would be viewed as magicians. With the wizardry of science, we could show them jet planes that can soar in the clouds, rockets that can explore the moon and planets, MRI scanners that can peer inside the living body, and cell phones that can put us in touch with anyone on the planet. If we showed them laptop computers that can send moving images and messages instantly across the continents, they would view this as sorcery.

But this is just the beginning. Science is not static. Science is exploding exponentially all around us. If you count the number of scientific articles being published, you will find that the sheer volume of science doubles every decade or so. Innovation and discovery are changing the entire economic, political, and social landscape, overturning all the old cherished beliefs and prejudices.

Now dare to imagine the world in the year 2100.

By 2100, our destiny is to become like the gods we once worshipped and feared. But our tools will not be magic wands and potions but the science of computers, nanotechnology, artificial intelligence, biotechnology, and most of all, the quantum theory, which is the foundation of the previous technologies.

By 2100, like the gods of mythology, we will be able to manipulate objects with the power of our minds. Computers, silently reading our thoughts, will be able to carry out our wishes. We will be able to move objects by thought alone, a telekinetic power usually reserved only for the gods. With the power of biotechnology, we will create perfect bodies and extend our life spans. We will also be able to create life-forms that have never walked the surface of the earth. With the power of nanotechnology, we will be able to take an object and turn it into something else, to create something seemingly almost out of nothing. We will ride not in fiery chariots but in sleek vehicles that will soar by themselves with almost no fuel, floating effortlessly in the air. With our engines, we will be able to harness the limitless energy of the stars. We will also be on the threshold of sending star ships to explore those nearby.

Although this godlike power seems unimaginably advanced, the seeds of all these technologies are being planted even as we speak. It is modern science, not chanting and incantations, that will give us this power.

I am a quantum physicist. Every day, I grapple with the equations that govern the subatomic particles out of which the universe is created. The world I live in is the universe of eleven-dimensional hyperspace, black holes, and gateways to the multiverse. But the equations of the quantum theory, used to describe exploding stars and the big bang, can also be used to decipher the outlines of our future.

But where is all this technological change leading? Where is the final destination in this long voyage into science and technology?

The culmination of all these upheavals is the formation of a planetary civilization, what physicists call a Type I civilization. This transition is perhaps the greatest transition in history, marking a sharp departure from all civilizations of the past. Every headline that dominates the news reflects, in some way, the birth pangs of this planetary civilization. Commerce, trade, culture, language, entertainment, leisure activities, and even war are all being revolutionized by the emergence of this planetary civilization. Calculating the energy output of the planet, we can estimate that we will attain Type I status within 100 years. Unless we succumb to the forces of chaos and folly, the transition to a planetary civilization is inevitable, the end product of the enormous, inexorable forces of history and technology beyond anyone's control.

WHY PREDICTIONS SOMETIMES DON'T COME TRUE

But several predictions made about the information age were spectacularly untrue. For example, many futurists predicted the "paperless office," that is, that the computer would make paper obsolete. Actually, the opposite has occurred. A glance at any office shows you that the amount of paper is actually greater than ever.

Some also envisioned the "peopleless city." Futurists predicted that teleconferencing via the Internet would make face-to-face business meetings unnecessary, so there would be no need to commute. In fact, the cities themselves would largely empty out, becoming ghost towns, as people worked in their homes rather than their offices.

Likewise, we would see the rise of "cybertourists," couch potatoes who would spend the entire day lounging on their sofas, roaming the world and watching the sights via the Internet on their computers. We would also see "cybershoppers," who would let their computer mice do the walking. Shopping malls would go bankrupt. And "cyberstudents" would take all their classes online while secretly playing video games and drinking beer. Universities would close for lack of interest.

Or consider the fate of the "picture phone." During the 1964 World's Fair, AT&T spent about $100 million perfecting a TV screen that would connect to the telephone system, so that you could see the person whom you were talking to, and vice versa. The idea never took off; AT&T sold only about 100 of them, making each unit cost about $1 million each. This was a very expensive fiasco.

And finally, it was thought that the demise of traditional media and entertainment was imminent. Some futurists claimed that the Internet was the juggernaut that would swallow live theater, the movies, radio, and TV, all of which would soon be seen only in museums.

Actually, the reverse has happened. Traffic jams are worse than ever—a permanent feature of urban life. People flock to foreign sites in record numbers, making tourism one of the fastest-growing industries on the planet. Shoppers flood the stores, in spite of economic hard times. Instead of proliferating cyberclassrooms, universities are still registering record numbers of students. To be sure, there are more people deciding to work from their homes or teleconference with their coworkers, but cities have

not emptied at all. Instead, they have morphed into sprawling megacities. Today, it is easy to carry on video conversations on the Internet, but most people tend to be reluctant to be filmed, preferring face-to-face meetings. And of course, the Internet has changed the entire media landscape, as media giants puzzle over how to earn revenue on the Internet. But it is not even close to wiping out TV, radio, and live theater. The lights of Broadway still glow as brightly as before.

CAVE MAN PRINCIPLE

Why did these predictions fail to materialize? I conjecture that people largely rejected these advances because of what I call the Cave Man (or Cave Woman) Principle. Genetic and fossil evidence indicates that modern humans, who looked just like us, emerged from Africa more than 100,000 years ago, but we see no evidence that our brains and personalities have changed much since then. If you took someone from that period, he would be anatomically identical to us: if you gave him a bath and a shave, put him in a three-piece suit, and then placed him on Wall Street, he would be physically indistinguishable from everyone else. So our wants, dreams, personalities, and desires have probably not changed much in 100,000 years. We probably still think like our caveman ancestors.

The point is: whenever there is a conflict between modern technology and the desires of our primitive ancestors, these primitive desires win each time. That's the Cave Man Principle. For example, the caveman always demanded "proof of the kill." It was never enough to boast about the big one that got away. Having the fresh animal in our hands was always preferable to tales of the one that got away. Similarly, we want hard copy whenever we deal with files. We instinctively don't trust the electrons floating in our computer screen, so we print our e-mails and reports, even when it's not necessary. That's why the paperless office never came to be.

Likewise, our ancestors always liked face-to-face encounters. This helped us to bond with others and to read their hidden emotions. This is why the peopleless city never came to pass. For example, a boss might want to carefully size up his employees. It's difficult to do this online, but face-to-face a boss can read body language to gain valuable unconscious information. By watching people up close, we feel a common bond and can

also read their subtle body language to find out what thoughts are racing through their heads. This is because our apelike ancestors, many thousands of years before they developed speech, used body language almost exclusively to convey their thoughts and emotions.

This is the reason cybertourism never got off the ground. It's one thing to see a picture of the Taj Mahal, but it's another thing to have the bragging rights of actually seeing it in person. Similarly, listening to a CD of your favorite musician is not the same as feeling the sudden rush when actually seeing this musician in a live concert, surrounded by all the fanfare, hoopla, and noise. This means that even though we will be able to download realistic images of our favorite drama or celebrity, there is nothing like actually seeing the drama on stage or seeing the actor perform in person. Fans go to great lengths to get autographed pictures and concert tickets of their favorite celebrity, although they can download a picture from the Internet for free.

This explains why the prediction that the Internet would wipe out TV and radio never came to pass. When the movies and radio first came in, people bewailed the death of live theater. When TV came in, people predicted the demise of the movies and radio. We are living now with a mix of all these media. The lesson is that one medium never annihilates a previous one but coexists with it. It is the mix and relationship among these media that constantly change. Anyone who can accurately predict the mix of these media in the future could become very wealthy.

The reason for this is that our ancient ancestors always wanted to see something for themselves and not rely on hearsay. It was crucial for our survival in the forest to rely on actual physical evidence rather than rumors. Even a century from now, we will still have live theater and still chase celebrities, an ancient heritage of our distant past.

In addition, we are descended from predators who hunted. Hence, we love to watch others and even sit for hours in front of a TV, endlessly watching the antics of our fellow humans, but we instantly get nervous when we feel others watching us. In fact, scientists have calculated that we get nervous if we are stared at by a stranger for about four seconds. After about ten seconds, we even get irate and hostile at being stared at. This is the reason why the original picture phone was such a flop. Also, who wants to have to comb one's hair before going online? (Today, after decades of slow, painful improvement, video conferencing is finally catching on.)

And today, it is possible to take courses online. But universities are bulging with students. The one-to-one encounter with professors, who can give individual attention and answer personal questions, is still preferable to online courses. And a university degree still carries more weight than an online diploma when applying for a job.

So there is a continual competition between High Tech and High Touch, that is, sitting in a chair watching TV versus reaching out and touching things around us. In this competition, we will want both. That is why we still have live theater, rock concerts, paper, and tourism in the age of cyberspace and virtual reality. But if we are offered a free picture of our favorite celebrity musician or actual tickets to his concert, we will take the tickets, hands down.

So that is the Cave Man Principle: we prefer to have both, but if given a choice we will chose High Touch, like our cavemen ancestors.

But there is also a corollary to this principle. When scientists first created the Internet back in the 1960s, it was widely believed that it would evolve into a forum for education, science, and progress. Instead, many were horrified that it soon degenerated into the no-holds-barred Wild West that it is today. Actually, this is to be expected. The corollary to the Cave Man Principle is that if you want to predict the social interactions of humans in the future, simply imagine our social interactions 100,000 years ago and multiply by a billion. This means that there will be a premium placed on gossip, social networking, and entertainment. Rumors were essential in a tribe to rapidly communicate information, especially about the leaders and role models. Those who were out of the loop often did not survive to pass on their genes. Today, we can see this played out in grocery checkout stands, which have wall-to-wall celebrity gossip magazines, and in the rise of a celebrity-driven culture. The only difference today is that the magnitude of this tribal gossip has been multiplied enormously by mass media and can now circle the earth many times over within a fraction of a second.

The sudden proliferation of social networking Web sites, which turned young, baby-faced entrepreneurs into billionaires almost overnight, caught many analysts off guard, but it is also an example of this principle. In our evolutionary history, those who maintained large social networks could rely on them for resources, advice, and help that were vital for survival.

And last, entertainment will continue to grow explosively. We sometimes don't like to admit it, but a dominant part of our culture is based

on entertainment. After the hunt, our ancestors relaxed and entertained themselves. This was important not only for bonding but also for establishing one's position within the tribe. It is no accident that dancing and singing, which are essential parts of entertainment, are also vital in the animal kingdom to demonstrate fitness to the opposite sex. When male birds sing beautiful, complex melodies or engage in bizarre mating rituals, it is mainly to show the opposite sex that they are healthy, physically fit, free of parasites, and have genes worthy enough to be passed down.

And the creation of art was not only for enjoyment but also played an important part in the evolution of our brain, which handles most information symbolically.

So unless we genetically change our basic personality, we can expect that the power of entertainment, tabloid gossip, and social networking will increase, not decrease, in the future.

SCIENCE AS A SWORD

I once saw a movie that forever changed my attitude toward the future. It was called *Forbidden Planet,* based on Shakespeare's *The Tempest.* In the movie astronauts encounter an ancient civilization that, in its glory, was millions of years ahead of us. They had attained the ultimate goal of their technology: infinite power without instrumentality, that is, the power to do almost anything via their minds. Their thoughts tapped into colossal thermonuclear power plants, buried deep inside their planet, that converted their every desire into reality. In other words, they had the power of the gods.

We will have a similar power, but we will not have to wait millions of years. We will have to wait only a century, and we can see the seeds of this future even in today's technology. But the movie was also a morality tale, since this divine power eventually overwhelmed this civilization.

Of course, science is a double-edged sword; it creates as many problems as it solves, but always on a higher level. There are two competing trends in the world today: one is to create a planetary civilization that is tolerant, scientific, and prosperous, but the other glorifies anarchy and ignorance that could rip the fabric of our society. We still have the same sectarian, fundamentalist, irrational passions of our ancestors, but the difference is that now we have nuclear, chemical, and biological weapons.

In the future, we will make the transition from being passive observers of the dance of nature, to being the choreographers of nature, to being masters of nature, and finally to being conservators of nature. So let us hope that we can wield the sword of science with wisdom and equanimity, taming the barbarism of our ancient past.

Let us now embark upon a hypothetical journey through the next 100 years of scientific innovation and discovery, as told to me by the scientists who are making it happen. It will be a wild ride through the rapid advances in computers, telecommunications, biotechnology, artificial intelligence, and nanotechnology. It will undoubtedly change nothing less than the future of civilization.

PHYSICS OF THE FUTURE
