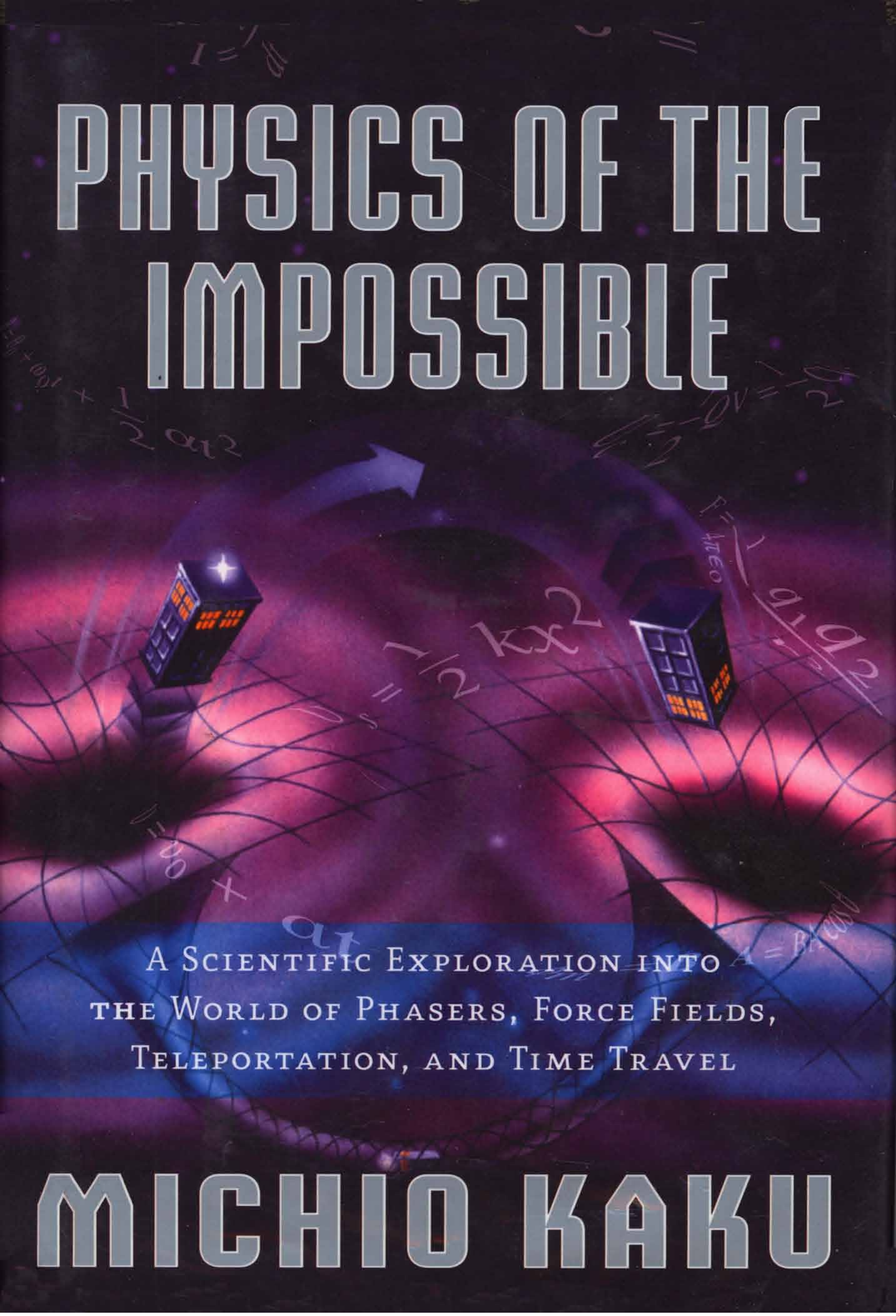
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MICHIO KAKU

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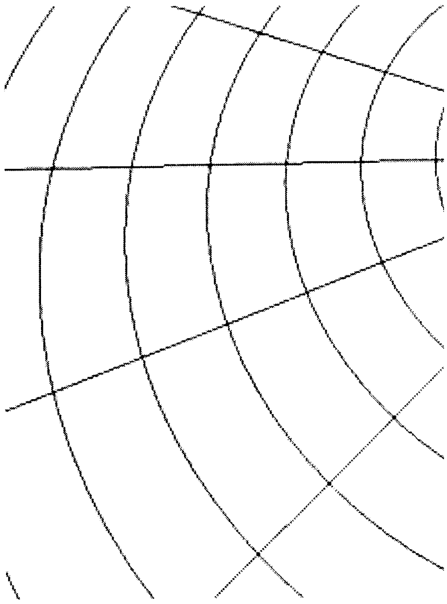

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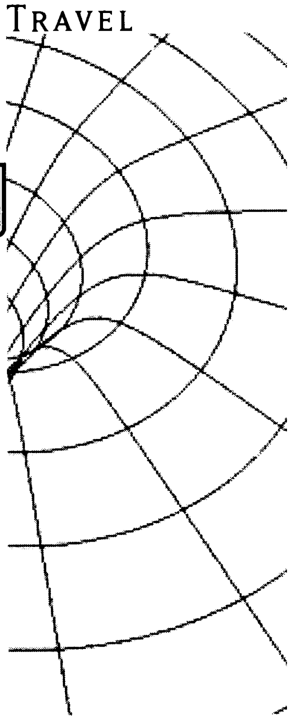

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First Edition

To my loving wife, Shizue,

and to

Michelle and Alyson

CONTENTS

PREFACE

If at first an idea does not sound absurd,
then there is no hope for it.
—ALBERT EINSTEIN

One day, would it be possible to walk through walls? To build starships that can travel faster than the speed of light? To read other people's minds? To become invisible? To move objects with the power of our minds? To transport our bodies instantly through outer space?

Since I was a child, I've always been fascinated by these questions. Like many physicists, when I was growing up, I was mesmerized by the possibility of time travel, ray guns, force fields, parallel universes, and the like. Magic, fantasy, science fiction were all a gigantic playground for my imagination. They began my lifelong love affair with the impossible.

I remember watching the old *Flash Gordon* reruns on TV. Every Saturday, I was glued to the TV set, marveling at the adventures of Flash, Dr. Zarkov, and Dale Arden and their dazzling array of futuristic technology: the rocket ships, invisibility shields, ray guns, and cities in the sky. I never missed a week. The program opened up an entirely new world for me. I was thrilled by the thought of one day rocketing to an alien planet and exploring its strange terrain. Being pulled into the orbit of these fantastic inventions I knew that my own destiny was somehow wrapped up with the marvels of the science that the show promised.

As it turns out, I was not alone. Many highly accomplished scientists originally became interested in science through exposure to science fiction. The great astronomer Edwin Hubble was fascinated by the works of Jules Verne. As a result of reading Verne's work, Hubble abandoned a promising career in law, and, disobeying his father's wishes, set off on a career in science. He eventually became the greatest astronomer of the twentieth century. Carl Sagan, noted astronomer and bestselling author, found his imagination set afire by reading Edgar Rice Burroughs's John Carter of Mars novels. Like John Carter, he dreamed of one day exploring the sands of Mars.

I was just a child the day when Albert Einstein died, but I remember people talking about his life, and death, in hushed tones. The next day I saw in the newspapers a picture of his desk, with the unfinished manuscript of his greatest, unfinished work. I asked myself, What could be so important that the greatest scientist of our time could not finish it? The article claimed that Einstein had an impossible dream, a problem so difficult that it was not possible for a mortal to finish it. It took me years to find out what that manuscript was about: a grand, unifying "theory of everything." His dream—which consumed the last three decades of his life—helped me to focus my own imagination. I wanted, in some small way, to be part of the effort to complete Einstein's work, to unify the laws of physics into a single theory.

As I grew older I began to realize that although Flash Gordon was the hero and always got the girl, it was the scientist who actually made the TV series work. Without Dr. Zarkov, there would be no rocket ship, no trips to Mongo, no saving Earth. Heroics aside, without science there is no science fiction.

I came to realize that these tales were simply impossible in terms of the science involved, just flights of the imagination. Growing up meant putting away such fantasy. In real life, I was told, one had to abandon the impossible and embrace the practical.

However, I concluded that if I was to continue my fascination with the impossible, the key was through the realm of physics. Without a solid background in advanced physics, I would be forever speculating about futuristic technologies without understanding whether or not they were possible. I realized I needed to immerse myself in advanced mathematics and learn theoretical physics. So that is what I did.

In high school for my science fair project I assembled an atom smasher in my mom's garage. I went to the Westinghouse company and gathered 400 pounds of scrap transformer steel. Over Christmas I wound 22 miles of copper wire on the high school football field. Eventually I built a 2.3-million-electron-volt betatron particle accelerator, which consumed 6 kilowatts of power (the entire output of my house) and generated a magnetic field of 20,000 times the Earth's magnetic field. The goal was to generate a beam of gamma rays powerful enough to create antimatter.

My science fair project took me to the National Science Fair and eventually fulfilled my dream, winning a scholarship to Harvard, where I could finally pursue my goal of becoming a theoretical physicist and follow in the footsteps of my role model, Albert Einstein.

Today I receive e-mails from science fiction writers and screenwriters asking me to help them sharpen their own tales by exploring the limits of the laws of physics.

The "Impossible" Is Relative

As a physicist, I have learned that the "impossible" is often a relative term. Growing up, I remember my teacher one day walking up to the map of the Earth on the wall and pointing out the coastlines of South America and Africa. Wasn't it an odd coincidence, she said, that the two coastlines fit together, almost like a jigsaw puzzle? Some scientists, she said, speculated that perhaps they were once part of the same, vast continent. But that was silly. No force could possibly push two gigantic continents apart. Such thinking was impossible, she concluded.

Later that year we studied the dinosaurs. Wasn't it strange, our teacher told us, that the dinosaurs dominated the Earth for millions of years, and then one day they all vanished? No one knew why they had all died off. Some paleontologists thought that maybe a meteor from space had killed them, but that was impossible, more in the realm of science fiction.

Today we now know that through plate tectonics the continents do move, and that 65 million years ago a gigantic meteor measuring six miles across most likely did obliterate the dinosaurs and much of life on Earth. In my own short lifetime I have seen the seemingly impossible become established scientific fact over and over again. 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 feats 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 were to somehow encounter a civilization a million years more advanced than ours, would their everyday technology appear to be "magic" to us? That, at its heart, is one of the central questions running through this book; 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 150 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 accidentally discovered by his great-grandson and published for the first time in 1994. In it Verne predicted what Paris might look like in the year 1960. His novel was filled with technology that was clearly considered impossible in the nineteenth century, including fax machines, a worldwide communications network, glass skyscrapers, gas-powered automobiles, and high-speed elevated trains.

Not surprisingly, Verne could make such stunningly accurate predictions because he was immersed in the world of science, picking the brains of scientists around him. A deep appreciation for the fundamentals of science allowed him to make such startling predictions.

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 (he is buried next to Isaac Newton in Westminster Abbey), declared that "heavier than air" devices such as the airplane were impossible. He thought X-rays were a hoax 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 smashers, 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 once 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 the Chandra X-ray telescope have revealed thousands of black holes in space.

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.

Studying the Impossible

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 radioactive decay, could indeed be kept molten for billions of years.

We ignore the impossible at our peril. 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 editors 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 a tremendous amount of energy locked deep inside the atom's nucleus, according to Einstein's 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. In the book he stated that the secret of the atomic bomb would be solved by a physicist in 1933. By chance Szilard stumbled upon this book in 1932. Spurred on 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 a 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 the 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 the "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 book 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 book, therefore, I divide the things that are "impossible" into three categories.

The first are what I call *Class I impossibilities.* These are technologies that are impossible today but that 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, certain forms of telepathy, psychokinesis, and invisibility.

The second category is what I term *Class II impossibilities.* These are technologies that sit at the 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 is what I call *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.

This classification is significant, I feel, because so many technologies in science fiction are dismissed by scientists as being totally impossible, when what they actually mean is that they are impossible for a primitive civilization like ours. Alien visitations, for example, are usually considered impossible because the distances between the stars are so vast. While interstellar travel for our civilization is clearly impossible, it may be possible for a civilization centuries to thousands or millions of years ahead of ours. So it is important to rank such "impossibilities." Technologies that are impossible for our current civilization are not necessarily impossible for other types of civilizations. Statements about what is possible and impossible have to take into account technologies that are millennia to millions of years ahead of ours.

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 as much beyond us as we are beyond a bush baby or a macaque."

In my own research I focus professionally on trying to complete Einstein's dream of a "theory of everything." Personally, I find it quite exhilarating to work on a “final theory” that may ultimately answer some of the most difficult “impossible” questions in science today, such as whether time travel is possible, what lies at the center of a black hole, or what happened before the big bang. I still daydream about my lifelong love affair with the impossible, and wonder when and if some of these impossibilities might enter the ranks of the everyday.

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Alan Guth, physicist, MIT, author of *The Inflationary Universe*

Part I

CLASS I IMPOSSIBILITIES