"Combining a childlike enthusiasm for discovery with a polymath's understanding of the natural world, Sy offers unusually clear explanations and insight into why it is important for us, not just the specialists, to know such things as how cells get their energy. For decades he saw the pursuit of truth through science as the height of life's purpose. What could top the joy of scientific exploration? Sy has an answer for this question too—discovering the God who created these wonders. As the book unfolds, he does not just show us that science and faith are compatible. He offers the story of his life to illustrate how the two together offer a new and much heightened view of life's purpose."

Paul Wason, vice president of life sciences and genetics at the John Templeton Foundation

"An arresting, wholly transparent account of a scientist's struggle with faith. There are many books of this sort, but almost none of this caliber or candor. Garte is a biochemist who competently explores physics, philosophy of science, quantum entanglement, mathematics, evolution, consciousness, and the fight for morality and justice, all in a fast-moving personal story that's quite funny at points and heart-wrenching in others."

Perry Marshall, author of *Evolution 2.0*, and founder of the Evolution 2.0 Technology Prize

"Sy Garte may be compared to C. S. Lewis in *Surprised by Joy.* As his pastor, I delighted in reading this personal narrative about Sy's transformation from an atheist to a believer in the triune God. His conversion was stimulated by his thoughtful inquiries as a scientist but completed by an encounter with the risen Christ. Sy found God only to realize that our gracious God had been wooing him with love and glimpses of joy for decades. A book worth reading by anyone who struggles with the intersection of science and faith."

Rev. Martha Meredith, pastor of Rockville United Methodist Church

"There are two pernicious myths about the Christian faith that circulate through modern culture. The first asserts that to become a Christian, one must park one's mind at the doors of the church before entering. The second myth is that senior academics set their foundational beliefs in stone early in their careers, and they remain intact until retirement. The spiritual and intellectual voyage of Dr. Sy Garte crushes both of these myths. Raised by parents steeped in communism and anti-theistic materialism, then educated in biochemistry and biological evolution, Garte spent much of his academic career as a fervent atheist. Yet an intuitive inkling that something was missing in his life—and in his science—opened the way for him to discover the grace of God in his Son, Jesus Christ. This book deals with many intellectually challenging issues Garte faced in his journey, including a renewed understanding of evolution as God's method of creation. Garte is a brilliant example of a Christian following Jesus's command to love God with our minds (Matt. 22:37)."

Denis O. Lamoureux, DDS, PhD, PhD, professor of science and religion at St. Joseph's College, University of Alberta

"In *The Works of His Hands*, biochemist Sy Garte shares what he learned (and is still learning) during his career as a scientist in search of purpose and meaning. He discovered Christianity, to paraphrase C. S. Lewis, as the 'light by which everything else may be seen.' His insights, offered in narrative and creative storytelling, provide a road map for reconciling science and faith, both for spiritual seekers peeking over the fence from the yard of agnosticism and for worried believers gazing out the chapel window at the so-called challenges of modern science. Thoughtful, provocative, playful, and intimate."

Stephen O. Moshier, professor of geology at Wheaton College

THE *works* OF HIS *hands*

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A Scientist's Journey from Atheism to Faith

SY GARTE, PhD

Kregel
Publications

The Works of His Hands: A Scientist's Journey from Atheism to Faith
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A portion of chapter 5 was originally published in "Teleology and the Origin of Evolution" in *Perspectives on Science and Christian Faith* (Boston: American Scientific Affiliation, 2017). https://network.asa3.org/page/PSCF?. Used by permission.

A portion of chapter 6 was originally published in "Evolution and Imago Dei" in *God & Nature* (Boston: American Scientific Affiliation, 2012). Used by permission.

ISBN 978-0-8254-4607-8, print
ISBN 978-0-8254-7584-9, epub

Printed in the United States of America
19 20 21 22 23 24 25 26 27 28 / 5 4 3 2 1

This book is
dedicated to
the love of my life,
my wife,
Anikó Albert

Great are the works of the LORD,
[they are] studied by all who delight in them.

The works of his hands are faithful and just;
all his precepts are trustworthy.
—Psalm 111:2, 7

Contents

Foreword

This remarkable book documents a journey of personal discovery and intellectual exploration, ranging over some of the greatest questions we face as human beings. Science and religious faith are often declared (generally by those anxious to shut down any discussion of the matter as quickly as possible) to be incompatible. It's an influential view, though resting on an outdated understanding of how we make sense of our world. In this engaging work, Sy Garte takes us on a myth-busting intellectual journey as he tells his own story of discovery and reappraisal, raising questions about some of the most deeply entrenched cultural certainties of our time.

Garte is lyrical in his praise of the natural sciences and helps us capture the sheer sense of wonder and intellectual excitement that accompanies a respectful and loving engagement with the world of nature. The work is shot through with beautifully crafted vignettes of scientific description—such as the role of quantum entanglement in photosynthesis.

Yet Garte, while celebrating the explanatory successes of the sciences, is alert to their limits. For a start, there are deep questions about meaning and value that science cannot answer. Yet the problems go much deeper than this. Garte highlights some fundamental questions about the rationality of our universe that arise from an appreciation of its "uncertainty and strangeness." Can human reason really hope to grasp the complexity of our world? For Garte, the philosophical implications of quantum physics and the role of chance call into question the "pure materialism" that is so often—and so wrongly—depicted as the natural default ontology of science.

How can such a materialist philosophy—something that is bolted on to the scientific method rather than being its essential foundation—help us account for our emotional reaction to our world, expressed using rich words such as *beauty*, *magic*, *passion*, or *joy*? While still an atheist, Garte found himself wondering where all this "emotional stuff" came from. Was there a better way of understanding our world, which could accommodate these important experiences plausibly and naturally? Garte's moving and engaging account of his "call of faith" weaves together his growing sense of the limits of a purely scientific knowledge and an awareness of the imaginative and rational appeal of Christianity.

The Works of His Hands thus leads us through two territories. The first is the world of the natural sciences; the second is the world of religion. Many unthinkingly assume these are incompatible or in a permanent state of warfare. Garte's story will cause many to rethink this long-outdated media trope and to reflect on how science and faith might get along better. Garte hints at the great Renaissance metaphor of the "Two Books of God" as he explains the harmony he finds between the two books of God's revelation to humanity, the Book of Words and the Book of Works. This timely and well-crafted book deserves to find a wide readership, especially among natural scientists who are weary of the sterility and superficiality of the "new atheism."

Alister McGrath
Andreas Idreos Professor of Science and Religion
Oxford University

Preface

There is a popular joke about a man caught in a flood who prays to God to be saved. He hears an answer to his prayer: "I will save you, My son." So with a glad heart, he waits for the miracle to happen. A boat comes by, and the people in it call for the stranded man to join them, but he says, "No, thank you. God will save me." And he continues to wait for the miracle. Two more boats follow (as in any good folktale), but his answer is the same.

The man drowns. When he gets to heaven, he confronts God: "Why didn't You save me like You promised?"

God says, "I sent you three boats. What more did you want?"

Here is another version of the story. Instead of a believer, our hero is an atheist. Caught in the flood, he thinks, *It sure looks like only a miracle could save me, but I don't believe in miracles, so I must save myself.* He dives into the swirling waters and tries to swim to safety. He sees a boat and hears people calling to him, but as a rational person, he knows that the chances of there being a real boat there just when he needs one are so small as to make such an occurrence essentially impossible. So he decides that the boat must be an illusion conjured up by his mind, and he continues swimming.

After he drowns, he also goes to heaven, where God asks him why he didn't get into the boat to save himself.

"Because it made no sense for there to be a boat there, and I used my reason to reject that possibility. Logic is stronger than belief in fairy tales," the man answers.

God smiles. "Yet here you are in heaven, in front of the real God who made you, as real as the boat that could have saved you."

God works through the natural world, and the natural world *is* the miracle.

The meaning of both parables is, of course, that God works through the natural world, and the natural world *is* the miracle. The first man expected an angel to come down, swoop him up, and carry him to shore. He rejected the possibility that an ordinary boat with a mortal human could be God's instrument of miraculous salvation. The second man assumed that his salvation was entirely in his own hands and rejected even the evidence of his senses that a miracle could happen. Some believers fail to see that the "mundane" world of nature, with its scientific laws, is itself divine—that is, flowing from God's will and character. They miss the miracle in everything around them, looking instead only to what they consider to be the rigid and unbendable Word of God. They share this blindness with many atheists who, like our second man, also find nature devoid of anything related to divinity, but they think of all reality as the rigid and unbendable consequence of arbitrary natural laws.

They are both wrong, of course, because God is not rigid or unbendable, and His laws of nature reflect this. The great gift of God to the universe is freedom. We see this when we examine the physical and the biological worlds in detail. God has created a universe in which the fundamental particles of matter have the freedom to exist in multiple states; it is only when they are observed that they make their "choice." As for life, God has created it in a way to allow a breathtaking diversity. There is freedom in evolution—freedom to explore, to succeed or fail. And God has granted His special creation of humankind the most freedom of all: freedom to make moral choices. To sin or to love; to worship or to scorn. To recognize that the boat is a miracle of salvation or to reject it.

My own salvation came through the understanding that the natural world—and its description by science—is a strong witness to God's existence and majesty. I did not reject the grandeur of this world as either too secular or too illusory to be important—I embraced it and devoted my life to scientific research. And that path eventually led me from atheism to faith (with a good deal of help from the Holy Spirit along the way).

In this book, I will try to show you how a belief in God the Creator should always be in tune with, and never opposed to, modern science. I will also tell you that matters of faith are not provable—and are not subject to proof in a scientific sense. This book was not written to convince anyone to adopt a certain set of beliefs. That is far from my interest. I have written this book more as a "guide to the perplexed" for people of faith (or open-minded atheists) who wish to embrace the modern world of science and technology and enjoy the intellectual and emotional beauty of science without giving up any part of their equally beautiful and soul-enriching faith in God.

As passionately as I try to follow the path of Jesus, and as fervently as I pray to God, giving thanks for His blessings in my life, I am equally passionate about the beauty and wonder of our natural world as revealed by the hard work, brilliant ideas, and beautiful synthesis of science. I find that these two passions are complementary and mutually reinforcing, and in fact may be two human definitions of a single unified passion, perhaps of divine origin.

My journey from atheism to Christianity was long and winding. I am telling it here because it might be of some use to those who find themselves wondering about the big questions of life. We will begin with some of these questions in chapter 1, which describes where

I started and how I discovered that questions are more important than answers.

The book is divided into two unequal parts. In part 1, I discuss how several scientific disciplines influenced me on my journey. Part 2 covers many of the issues and questions I faced once I had become a follower of Jesus Christ.

In chapters 2 and 3, I talk about some of the surprising and not widely known scientific realities that first got me thinking that the alleged dichotomy between reason and faith might not be real.

Chapter 4 is where I indulge my love for biology and attempt to explain how life works. The living activity in a tiny ribosome is a testament to God's magnificence on a par with the birth and death of galaxies. There is some technical detail in this chapter, although I have put more details in a technical appendix for those with special interest in the subject matter. Chapter 5 is devoted to evolution: what it is not, what it is, and how it works. Chapter 6 is about my favorite species: us. Human beings are special. Yes, I am an unabashed believer in human exceptionalism, and I will try my best to make a case for it in this chapter—or at least to thank God for being made in His image.

Throughout these chapters, I weave together the story of my growing awareness of God with my growing understanding of the scientific ideas that I was learning about at the same time. In chapter 7, I approach some of the philosophical ideas I discovered on my journey. I talk about the three great origins—the origins of the universe, life, and humanity—for which science cannot offer ultimate explanations. Chapter 8 is about the limits of science and the things we know that we cannot know scientifically.

Finally, in chapter 9, I leave science and talk in more detail about my own journey. This is the most personal chapter in the book, and it is meant to be read as one of many such stories about how Christ and the Spirit can move us to faith.

Part 2 begins with two chapters (10 and 11) that fill in some of the details about what happened when I became a Christian and how I sought and found answers to a whole new set of questions related to faith. In chapter 12, I discuss some of the controversies about evolution from a Christian viewpoint, explore the expanding new ideas in evolutionary theory, and have a closer look at the evolutionary creationist worldview. Chapter 13 provides a summation of where I am today as a scientist and deeply committed follower of Christ. Finally, chapter 14 is a short conclusion and a prayer of thanksgiving to our Lord and Savior.

I have included appendices with suggestions for discussion questions (appendix A) and further reading (appendix B), as well as one that provides more detail on some of the material touched on in chapter 4 for those with a deeper interest in biology (appendix C). There is also a short description of how I made an interesting discovery about Darwin while visiting the British Library in appendix D.

Science is distilled doxology.

Within the text there are four stories, written in the form of fables, that attempt to illustrate points I am trying to make in a (hopefully) amusing way. Some readers might feel that these fables are irreverent, or perhaps even verge on the sacrilegious—if that is the case, I apologize. Please know that I love God, and if I take any liberties for the sake of being a bit more lighthearted, this should not be taken as a sign that my devotion to the majesty of our Lord is less than profound.

To summarize in a few words what I am trying to convey: science discovers and describes natural laws, and natural laws come from

God. Science is distilled doxology. Now, let's start at the beginning and see where I came from and how I began to ask the questions that led me to begin my journey to God.

PART 1

Getting There

CHAPTER 1

The Importance of Questions

Like many folks, I absorbed my first religion from my parents. It was an unusual religion for an American. It had nothing to do with God, but it was dogmatic, doctrinaire, and authoritarian. It had its own moral code, its own saints, and its own schisms. It was based on faith, and it suffered from a history of inherent contradictions and failures. It was communism.

My grandparents were Russian Jewish immigrants and revolutionaries. A granduncle fought in the Russian Revolution. Another granduncle founded the furriers union. My grandfather was a leading communist organizer in Boston who knew radical leaders like Nicola Sacco and Bartolomeo Vanzetti and helped found the upholsterers union. One grandmother was an important member of the International Ladies' Garment Workers' Union. My parents were card-carrying members of the American Communist Party in the 1930s and '40s. My sister joined picket lines for Julius and Ethel Rosenberg (who were executed as communist spies). I was briefly the president of the Students for a Democratic Society chapter of my college, and I participated in numerous marches and demonstrations for civil rights and against the Vietnam War. I was at the

Columbia and City College of New York campus takeovers by radical students in 1968 and 1969.

As for traditional religion, it was of course absent from my upbringing. I had no bar mitzvah at age thirteen. I never set foot in a synagogue, church, or temple, never attended Hebrew school, never celebrated any holiday except New Year's Day (which was condoned by the Soviet authorities as an acceptable time to give presents to kids) and of course May Day and Labor Day (in a quiet way). In December we had no Christmas tree, no menorah, no songs, no celebrations. I was one of the first kids in America to say "Season's greetings" instead of "Merry Christmas." In the spring, we avoided Easter egg hunts and never had or even attended any seders.

My parents quit the Communist Party just before my birth, but they remained committed to the political and anti-religious philosophy of Marxism and were strongly opposed to anything that smacked of spirituality or transcendence. They laughed at the idea of God. They were sure that there was no God; there could be nothing like God; God could not possibly exist. But they did not stop there. Like many of the modern anti-theists, my family thought of religion as not only wrong but evil. Religions were based on lies and had the explicit purpose of enslaving and oppressing humanity throughout history. My parents' atheism was indeed a deeply felt religious belief, and it was successfully transmitted to and accepted by me at a very young age.

Like all faiths, the faith I was born into raised questions. And like all faiths, mine had ready answers for most of these questions. Why are we here? What is our purpose? The answer to these were clear: to work for the betterment of all humanity, to strive for fairness and justice in the world for all, to defeat the evil forces of superstition, oppression, and hatred. Good answers.

But even early in my life, I sensed a problem with them. If there is no concept of fairness in nature, and if humans are nothing more than natural beings, why should they be fair?

Where did the subversive concepts of fairness and justice come from? What was their source if it wasn't from the natural world?

If there is no absolute moral standard, why is it important that there be no starving children, no families decimated by the ravages of capitalist-imperialist warfare, no slaves, no oppressed workers suffering from degradation at the hands of greedy, self-satisfied, oppressive capitalists? After all, aren't those capitalists simply acting out in extreme the pseudo-Darwinist prerogative of survival of the fittest? Justice and mercy were part of the background of my youth. "It isn't right that Negroes can't ride in the front of the bus." "Workers can't get justice." "It isn't fair that the colonialists take all the resources from the countries they exploit." But where did the subversive concepts of fairness and justice come from? What was their source if it wasn't from the natural world?

The answer I came up with was that humans had somehow evolved to a higher level in the midst of a cruel and uncaring world, that humans had evolved a sense of purpose and a potential for further growth and development. I felt that through an evolutionary quirk (what Richard Dawkins later referred to as a "spandrel"), humans had become a unique species of animal that could feel, think, and create. I understood that we humans had evolved from the natural world, but I also came to see that we were something more. We could create beauty, we could change our lives, we could love. But these were vague and uncertain ideas, pretty well lost in the maelstrom of anti-religious views that dominated my mind.

As a young man, I would never have thought that I could possibly become a theist. I subscribed to all the arguments against religion. I found the following especially convincing:

- If there is a God, why doesn't He show Himself or provide some evidence of His existence?
- Religion has been an evil force in history.
- A belief in the supernatural is irrational, not provable, and not falsifiable, and it is based only on unreliable subjective experience.
- The claims of Christianity—life after death, resurrection, and miracles—are magical and scientifically impossible; they violate the laws of nature.
- The Bible is a book of mythical fairy tales filled with bad science, bad history, and the terrible deeds of a jealous, angry god figure and his people.

These arguments have become even more popular today. One can find them from comedy sketches to the writings of academics and intellectuals, not to mention all over the internet. It took me a very long time to discover that they were all false.

Why Questions Count

What questions we ask can change the very way we see the world. I first learned about the importance of questions when I became a research scientist. All scientists eventually learn that answers are easier to find than the right questions. The best scientists are those who find the right questions (either through brilliance or luck). One can waste decades finding answers to questions that are not very important or interesting, whether they are about science or about faith. In my case, asking questions about the faith I grew up with—faith in Comrade Stalin—and the atheist worldview was critical to my being able to reject such ideas and search for better answers. Some of those questions are listed at the end of this chapter. But before we get to that, let's take a look at some of the critical questions in science that eventually led to a major revolution in how we think about the nature of reality.

There was a time in the history of science when many people thought that there were no more new questions to be asked—that almost every worthwhile question about nature had been answered. Phrases like "there is nothing more to be discovered in physics" and "all that remains is more precise measurement" reflect the sentiments of many scientists at the turn of the twentieth century. Albert Michelson said, "While it is never safe to affirm that the future of Physical Science has no marvels in store even more astonishing than those of the past, it seems probable that most of the grand underlying principles have been firmly established."[1] He went on to say that future work in physics will be largely filling in data on the "sixth place of decimals."

It was widely believed (with some dissension) that all of the basic theoretical understanding of the universe had been discovered. The final brilliant stroke had been the work of James Clerk Maxwell on electricity and magnetism. Maxwell's famous equations showed how these two mysterious forces were interrelated and how the concept of fields (magnetic fields and electrical fields) could explain the behavior of many physical phenomena, including light. The general view was that even if there were a few details to fill in (e.g., all of biology), it was clear that the scientific method had been successful in its attempts to understand nature. We were at the point of knowing everything.

There was, however, an important missing piece in the fabric of human understanding of nature: confirmation of the existence of the ether. The ether was believed to be an invisible, intangible substance that permeated space and was supposed to be the medium through which light traveled at such immense speed. At the time, scientists thought of light as simply a wave, and waves always require some medium in which to move. For example, water is the medium for the motion of ocean waves, and air is the medium for sound waves.

In 1887, Michelson and Edward Morley did an experiment designed to find tangible evidence for the ether. What they found, contrary to their expectation, was that the speed of light was the same regardless of its direction. This suggested that there was no ether, but it left the question of how light traveled unanswered. The speed of light had been measured and was known to be a constant. But without an ether to travel in, it wasn't very clear how light could be a wave. And if not a wave, what was it?

Einstein found the answer, but it was not something easy to grasp. The movement of light turned out to be an exception to everything known about relative motion. In our normal experience, if you are sitting on one train, and your friend is going in the same direction on another train on a parallel track at the same speed, you can wave and smile and hold up signs if you want, since relative to her, you are not moving. But if the train is going the other way, you have no chance of even seeing her, since her speed relative to yours will be double your actual speed. This is also true of sound waves and everything else that moves. But the speed of light is constant for an observer whether the observer is moving toward or away from the light. Why is light different? Einstein's shocking answer had to do with the nature of time. In fact, the truth is that the speed of light is always constant because time is not.

Einstein's theory of special relativity provided an explanation for the nature of light and time that lies outside of our normal experience. He proposed that time can slow down or speed up depending on how fast you move. I don't mean that an hour in the dentist chair seems to last much longer than two hours at the movies with your lover. What Einstein predicted was that if you put a clock on a spaceship and had it fly very fast for what was an hour on earth, when it came back, that spaceship clock would show that less time had passed, perhaps fifty-nine minutes, even less as the spaceship approached the speed of light. In other words, actual time itself, not our perception of time, literally slowed down on the spaceship compared to time here on earth. The idea of time slowing or speeding up is a principle of physics that defies our commonsense experience. But it turns out to be demonstrably true, confirmed by many experiments. For example, Joseph Hafele and Richard Keating showed in 1972 that clocks flying eastward on a jet lost time compared to reference clocks on the ground, while those flying westward gained time, as predicted by Einstein's theory.

The famous end-of-physics assessments by Michelson and others were wrong. The theory of special relativity was only the beginning of an enormous revolution in physics that transformed the way scientists view reality. This revolution has been slow to enter the public consciousness, and its philosophical implications have been only marginally addressed. The problem is that so many of the answers to the new questions being asked at the start of the twentieth century were not only strange but seemed to undermine reason, logic, and common sense—the very foundations of science itself.

When I first learned about relativity and quantum mechanics (see the next chapter), I understood that a lot of what I had taken for granted might not be true and that in fact there was an important question that needed to be asked: *Is our world a purely logical and rational place that is fully understandable by the application of reason?*

I had learned that the obvious answer to this question must be yes, as required by the strictly materialistic, philosophical naturalism I was brought up to believe in. But as I read and learned more about physics and other sciences, including my own field of biology, I began to see that the answer to this question might be no.

It's important to clarify that this question is not inspired by current gaps in knowledge. The facts that we do not know at this time how to prevent or cure cancer, or how gravity is connected with quantum theory, or even how to make a computer that does what you want it to do (instead of what *it* wants to do) are not part of this question. Think about all the things we did not know just a few decades ago and then learned using science. The question is not about what we do not know, but about the nature of what we *do* know.

Before we proceed with an answer to this question, I want to show you some of the other key questions that arose in my mind while pursuing my studies and then later during my career in science. None of them are especially original, and many scientists shrug them off when asked. I did the same thing for a long time. But at one time or another, they all came back to haunt me, and the search for their answers led me along one very particular path. Each is addressed in chapters 2 through 9.

Is our world a purely logical and rational place that is fully understandable by the application of reason?
Why does every answer we get from research into any branch of science always lead to more questions?
Why is complexity the rule in nature?
Why is biological life so complex?
Is evolution by natural selection the best theory to explain how life became so diverse and complex?
Are human beings special, and if so, how did we get that way?
How did the universe, life, and human consciousness arise?
How do we go beyond the limits of the scientific approach to understanding and knowledge?
Aren't science and religious faith opposites and enemies?

These questions mark the milestones in my journey. I did find some answers to these questions, and I am still finding more. It took me a long time to arrive at these answers, and I will chronicle that journey in the rest of this book. Some of the ideas that I now believe answer those questions came from my scientific studies or awareness; others came from my growing appreciation of nonscientific paths to knowledge and truth. None of them contradict any scientific principles, but many of them lie outside of science. This means that before I could make any progress, I needed to answer a question that is the converse of the first one I asked: *Can we learn anything about our world without using the methods, tools, and results of scientific investigation?*

I concluded that we can. To understand how I came to that conclusion, and to learn how I resolved the other questions, you will need to read on.

CHAPTER 2

The Irrational World of Modern Physics

Is our world a purely logical and rational place that is fully understandable by the application of reason?

Logic and reason are good things, and they have been of great help to humanity during our long struggle to climb from ignorance to scientific truth and a better way of living. But they go only so far when it comes to understanding the natural world. It turns out, much to the surprise of scientists like myself, who had been trained to believe that mysticism was sheer nonsense, that reality can be downright mystical.

I took physics and physical chemistry in college, and in the latter course, I learned about the Schrödinger equation, one of the basic building blocks of quantum mechanics. (I even got one of my very few As because on the final exam I somehow was able to use this equation in a way that impressed my professor, netting me a grade of forty-seven, the highest in the class.) I also learned the fundamentals of Planck's theory of the discrete, noncontinuous "packets" of energy that he called "quanta" (plural of quantum; see below). But like my fellow students, I saw nothing of philosophical interest in this material. It wasn't until a decade or so later, when I began reading books like *The Tao of Physics*, that I began to wonder about what it really meant that reality was based on some very strange science.

Chance, Determinism, and Baseball Cards

There are a number of strange things about the universe that science has uncovered in the past century, and among the strangest is the behavior of the tiny particles that ultimately make up everything. These particles (like electrons and photons) obey different laws than the everyday objects that occupy the classical universe we are familiar with. Their behavior is stochastic, meaning that it is based on probability: no matter how much we know, we cannot predict their future behavior with certainty.

We think of tossing a coin as a good model for a random probabilistic system, but that is just what it is—a model, not a true stochastic system. The outcome of a coin toss is actually deterministic: if we knew everything possible about the way the coin is flipped, we could predict the outcome. I have personal experience with this kind of system, since my friends and I carried out (and replicated many times) very successful experiments on it when I was about twelve years old. We all collected baseball cards that came in bubble gum packages and were randomly selected, but some of them (like Mickey Mantle or Duke Snider) were much more valuable than others. So we played a game that allowed us to capture (or lose) these valuable cards from each other. One kid would flip a card into the air, which would land on the ground either picture up (heads) or down (tails). Another kid would flip one of his cards. If the second kid matched the result of the first card flip (heads or tails), he got to keep both cards. If he got the opposite result, he lost his card.

You would think that this would be a fair, random game of chance. It wasn't. After a great deal of practice (about ten times the amount of time I spent on doing homework), I was able to flip cards in a way that gave me the heads or tails I needed to win. I don't know how I did it, but it worked. In fact, we all were able to do it. I was able to flip up to fifty heads (or tails) in a row. The collection of baseball cards I amassed (later thrown away by my mother, as happened to everybody I ever met) was quite impressive.

Theoretically, the same thing is possible for coins or dice (though a lot harder, unless we cheat and load them). But not for electrons or photons. No matter how hard we work, no matter how precise our technology gets, we cannot predict the behavior of individual elementary particles. The reason we know that these particles behave in a very different way from anything we are used to seeing or touching is the development of a theory of physics about eighty years ago that was as strange as it was revolutionary: quantum mechanics (QM).

Quantum Mechanics

The turn of the twentieth century saw physics as it was then known overturned by several startling developments. Max Planck discovered that the only way to explain some kinds of radiation was to assume that energy could only be emitted in a noncontinuous way, as a series of packets rather than a stream. The size of these packets, or quanta, was equal to the frequency of the wave times a constant (later called Planck's constant, *h*). Planck found that the amount of energy in a wave was equal to any whole-number multiple of the frequency times *h*: it could be 1, 2, or 3 times that value, for instance, but not 2.8 or 3.1 times. In other words, reality at this level did not appear to be smooth, continuous, and infinitely divisible.

Soon after, Niels Bohr demonstrated that electrons in an atom could only exist at these same discrete quantum energy levels, and Einstein found that light energy also came in these discontinuous packets of energy. Quantum theory was on its way to revolutionizing physics and challenging the scientific philosophy of existence.

When these ideas were first proposed, most scientists found them disturbing. The idea of a noncontinuous universe seemed to fly in the face of everything that science had learned up till then. Space was assumed to be as infinitely divisible as the mathematics of rational numbers used to measure it. Newton's laws of motion and all the laws of chemistry and energy were based on continuity. Nobody could imagine covering a distance from one point to another without passing through all the points in between, or heating something without seeing a gradual rise in temperature through all degrees between the original temperature and the final one. But Planck and Bohr had found that that's exactly what happened on the atomic scale. An electron could move from one energy level to another one, instantaneously, without passing through all the intermediate levels on the way.

But that was only the beginning. As physicists began to explore the ramifications of the quantum model of the atom and what it meant for matter and energy, things just kept getting crazier. Among the facts this new physics brought out was one that even Einstein refused to believe for a long time: at the very small level of reality where the quantum rules hold, everything is truly probabilistic and not determined. In other words, randomness is the rule, not just an apparent effect of our inability to predict how a coin will fall.

Quantum theory revealed that particles like electrons and photons do not actually exist as fixed points in space and time. Before any measurements are made, a particle exists in a probability density, in several "superposed" potential states. Once an observation is made (we measure a position, determine a mass, or detect a velocity), one of the potential states becomes "fixed" as the actual state.

This quantum "observer effect" is not simply attributable to perturbations caused by the detectors or measuring devices. It is not, for example, that detectors that are placed at the end of a pathway interfere with the beam along its path. In 2000, an experiment was conducted that proved that the mechanics of observation is not changing the phenomenon. Instead, the observer is somehow determining an after-the-fact reality based solely on the act of observing.

Consciousness is a basic and necessary ingredient of reality.

Think about what this means. If observation is a critical part of existence, and the observer is either a conscious being or an instrument used by a conscious being that records or measures the system under investigation, then consciousness is hardly a murky and inconsequential quality of human (and possibly other animal) minds. Rather, it looks like consciousness is a basic and necessary ingredient of reality.

In his book, *Quantum: Einstein, Bohr, and the Great Debate About the Nature of Reality*, Manjit Kumar discusses the detailed history of the development of quantum mechanics: “It was Heisenberg, in his uncertainty paper, who first advocated in print the rejection of one of the central tenets of science.”[1] The author quotes from Heisenberg’s paper. Heisenberg asserts that the central tenet of science is this: “When we know the present precisely, we can predict the future.” Heisenberg labels this statement as an assumption, not a conclusion, and states that the assumption is *false*. Not only that, but he claims, “Even in principle we cannot know the present in all detail.”

This was a revolutionary statement, and as further work proved it to be true, the scientific view of reality changed forever.

Many other scientists have made statements that reflect the mind-bending philosophical implications of QM. Here are a couple of quotes from two of them.

> It is a striking fact that almost all the interpretations of quantum mechanics . . . depend to some degree on the presence of consciousness for providing the "observer" that is required for . . . the emergence of a classical-like world.
>
> —Roger Penrose[2]

> In the beginning, there were only probabilities. The Universe could only come into existence if someone observed it. It does not matter that the observers turned up several billion years later. The Universe exists because we are aware that it exists.
>
> —Martin Rees[3]

Quantum Entanglement

Quantum physics reveals other very strange twists in a modern scientific view of nature. In quantum entanglement, two particles are linked in such a way that their states cannot be described independently of each other—anything that affects one particle instantaneously affects the other one as well, even if they are light-years apart. This violates what classical physics calls the principle of locality: causation requires that something carries the influence through space from one object to the other, and since we know that nothing can move faster than the speed of light, instantaneous causation should be impossible. Einstein, disturbed by the implications, initially dismissed quantum entanglement as "spooky action at a distance,"[4] and others have called it "the God Effect,"[5] but it is real and demonstrable.

If you think all of this is crazy, you are not alone. The scientists who discovered and studied quantum mechanics agreed. Here are a couple more quotes.

> It is no longer possible to make predictions without reference to the observer or the means of observation. To that

> extent, every physical process may be said to have objective and subjective features.
>
> —Niels Bohr[6]

> The *actual and individual object* of classical physics is replaced by a more abstract kind of *potential and statistical object*.
>
> —David Bohm[7]

The world we experience, the world we can see and feel and touch, is ruled by what we now call classical physics, or the world of Newton. In this world, reason and common sense prevail: things are what they seem, and they behave the way we expect them to behave. But now we know that the submicroscopic world of atoms, photons, and other elementary particles is ruled by quantum physics, which requires an irrational kind of interaction or dialogue between the particles, their surroundings, and the person studying them.

Fundamental Uncertainty Is a Certainty

Werner Heisenberg proved that it was impossible to determine the *position* and the *momentum* of an electron at the same time. The more precisely we know one, the less precise we can be about the other. Heisenberg's uncertainty principle was the first blow to the idea, gained after so many decades of relentless scientific progress, that eventually we would be able to know everything.

If the quantum rules applied to everyday life, we would be in deep trouble. Perhaps I wanted to take a ride, but there was no way to know whether my car was in the garage until I opened the door. And then I might see it there, or maybe I wouldn't—not because of the vagaries of crime or perhaps a late night at a bar ending in friends having to drive me home, but merely due to the deep, underlying nature of cars in garages. If I were lucky and my car were there, I could get in and drive, but I would not be able to tell how fast I was going as long as I knew where I was. Alternatively, if I knew my speed, I would not know where I was. To make matters worse, I might suddenly find myself linked to some other person or object out there in the universe whose state of being directly affected what I did. I might suddenly stand up for no apparent reason, simply because a pangolin in southern China decided to lie down. And so on.

Such strange phenomena that are part of the reality of nature at the smallest and most fundamental level make it difficult to maintain philosophical materialism as the one legitimate way to view reality. You might ask, then, why so many atheists continue to worship at the altar of reason and logic. I don't know the answer, but I do know that few of those who do are physicists.

I was still a committed atheist when I first read about QM, the observer effect, and the uncertainty principle as a young adult. I was as badly shaken in my faith in rationality as were the physicists who heard about these new ideas from Bohr and Heisenberg in the 1920s. Not knowing much physics (beyond the introductory courses I mentioned), I couldn't grasp the mathematical logic behind the theories, but I wondered what all of this meant for my worldview. I had to reject some of the critical components of a comfortable theory of atheism. One was that the world was a rational place described by rational laws. I had discovered that the basic principles of modern physics, from relativity to quantum mechanics, describe a world of reality that seems irrational to us. If *imaginary* and *irrational* are truly critical adjectives needed to give an accurate scientific description of nature, how can the labeling of anything as imaginary or irrational (such as God) be an indication of nonexistence?

I also started to doubt that we humans can use our talents to eventually attain total and complete knowledge of everything. I was still an atheist, but I was no longer a smug and comfortable one. Science itself had opened cracks of doubt in my sense of certainty.

We might wonder why the universe was created with this kind of uncertainty and strangeness. We cannot know the answer, but maybe it was something like what transpires in the following fable. (Note: this story—like all the fables in this book—is not to be construed as actual or in any way serious theology, but only as a thought experiment.)

A Fable About the Origin of Chance

After many attempts, God finally made the perfect universe. Everything worked great: the stars shone, the sun was brilliant; plants and animals, birds and fish were everywhere; and humans were happily living in the garden of Eden. There was no sin, no death, no misery, and no surprises. God looked at His creation and saw that it was perfect.

But now that God had gotten everything right, including those pesky laws of physics with their infernal constants [see chapter 8], there wasn't much for anyone in heaven to do. Satan kept himself busy by trying to tempt some humans, but he had no success. They always smiled and turned down his offers. Apparently, none of them were very curious about the Tree of Knowledge of Good and Evil or interested in disobeying the Master of Creation.

As the years and millennia rolled on, not much happened. The snake kept running around like all the other reptiles, and the humans kept loving each other, smiling, and praising God. They also sang a lot and played with each other. One day, the archangel Michael was hanging out on earth, watching a small group of humans who seemed to be amusing themselves quite a bit. They had invented a new game where they would take different sized sticks and throw them around, and depending on how and where they landed, they did something or other, which often made them laugh. While watching, Michael saw that the humans apparently had no idea where the sticks would land. At first he found that strange, until he remembered that humans were not very smart and probably were not able to predict how the sticks would fall based on the precise configuration in which they were held, the wind speed and direction, and the force and direction of the throw.

None of this was a problem for Michael, of course, but then he was an angel. He envied the humans their excited anticipation and cries of joy or disappointment at the results of the game, and he wondered if he would be happier if he were more stupid. But then he had the germ of an idea.

"Satan!" Michael called out after returning to heaven. "I want you to hear something. I have had an idea."

Satan came over and said he couldn't wait to hear Michael's latest idea.

"Maybe we should ask the Boss to try out one more universe, different from this one."

"Different how? This one is perfect."

"Yeah, but it's so boring." And then Michael told Satan about the game he had seen.

"Yes, I have seen that also. They call it a game of chance."

"A game of what?"

"Chance. That means they aren't smart enough to calculate future events based on causation." Michael nodded, then pitched his idea: "But what if the Boss made a universe where chance was really real, I mean even for us?"

Satan thought about it. "You mean, no laws of physics? How else could you do away with determinism?"

Michael didn't know, but suggested they take the idea upstairs.

As it turned out, God (omniscient as He is) had been thinking along the same lines for other reasons that are beyond the comprehension of either the readers or the writer of this tale. Satan made the case for a world where random chance played a big role.

God liked the idea and began to think of a way He might do it. I don't know how long it took God to think of the answer because God is not that connected to time, so it's really hard to say. But at some point He called His angels together and said: "OK, I am going to try again. Let's see how it goes."

And that's how quantum mechanics were born.

As soon as the new universe was built, God looked at it with satisfaction. "Not perfect this time, but good."

Satan saw the two people in the garden and got ready for his latest temptation attempt.

"Will this one be different, Lord?" he asked the Boss. After all, God could see the future as well as the present.

God smiled. "Oh yes, it will be. And I promise you one thing: it won't be boring."

Of course, we have no idea why God designed our universe to be based on chance, but it probably had nothing to do with the plot of the fable. We do know that the world works, and although it is indeed not perfect, it is just possible that it works as well as it possibly could. We don't know how well a strictly deterministic universe would function, but God does (maybe because He tried it?), and that's my point.

Does the discovery of the uncertainties of QM mean that reason and logic have no place in science? Or is QM, with its mystical results and otherworldly conclusions, a sign that scientific thinking is dead or no longer useful? No, of course not. Quantum theory is good science, and our inability to "understand" it with our limited senses and intuitions meant for the world of everyday objects we live in does not mean it is not true or that science cannot account for it. It can, and it does, and it turns out that QM is demonstrably real and very important in that same world.

For instance, we are finding out that QM plays an integral role in one of the biggest mysteries in biology: the mechanism of photosynthesis. All life on earth depends on photosynthesis. It was the process of photosynthesis that gave rise to oxygen gas in the atmosphere, and without photosynthesis, animals would have nothing to eat.

In the past few years, experiments have indicated that it is because of quantum entanglement that photosynthetic bacteria and plants are able to convert light energy to chemical energy with sufficient efficiency to allow for biological growth. I will discuss photosynthesis more in chapter 4—I will only say here that part of the process involves the release of an electron that tries many possible chemical pathways simultaneously to find the most efficient way to achieve conversion to chemical energy.

This is quite remarkable. It suggests that quantum entanglement, far from being an esoteric property of particles in labs, is probably the most important physical phenomenon we know of when it comes to life. No entanglement, no people. If it is true that entanglement defies our notions of normal cause and effect and suggests the existence of phenomena beyond our ordinary human understanding, I think it is quite amazing that life on earth is totally dependent on the reality of this extraordinary, even "godly" effect.

Photosynthesis is not the only part of life that works according to a quantum design—so does inheritance. The quanta are the packets of information we call genes. We cannot predict how the offspring of two parents will appear, since the characteristics of the offspring will depend on the chance of which packets (genes) are passed to the new individual. Biology is ultimately based on the stochastic model that quantum theory implies. Even the sex of a child is determined by random chance based on transmission of a bundle of quantum genes in the form of a chromosome. Mutations (which I will discuss more in later chapters) are generally random occurrences.

By the time I finally understood the philosophical implications of quantum physics and the role of chance, I had pretty much jettisoned my belief in a pure materialism, and I found myself in a state of uncertainty (much like an electron) regarding my worldview. But before we get too carried away with the idea that everything in our universe is based on pure chance, we need to remember an important point. It is true that stochastic phenomena apply to individuals in a population or collection of organisms, particles, or human beings; however, in aggregate, for the entire population or collection, things are very predictable and deterministic. This is why even though we cannot say anything predictive about the motion of a particular gas molecule, we can describe the behavior of the gas in a container with great accuracy. The same holds true for rules that govern everything from electrons to ant colonies to human populations: chaotic behavior on the part of individuals becomes regular in large aggregates. And this is why we can formulate scientific laws.

But not always. There are some aspects of our world that defy simple solutions, even when dealing with everyday matters like ecological dynamics, the shapes of things, coastlines, and that pesky subject that affects us in so many ways—the weather. As we will see in the next chapter, science is just full of surprises.

CHAPTER 3

Science Surprises

Why does every answer we get from research into any branch of science always lead to more questions? Why is complexity the rule in nature?

As a young atheist, I studied biochemistry and found myself emotionally drawn to the beauty and basic order of science. The way cells work is so magnificent that learning about it always gave me a thrill. When I studied and later taught the mechanism by which proteins are made in cells, I always felt a chill down my spine. I was told once by a student that my voice, my body language, and my tone of conviction when I described how ribosomes, tRNA, and all the components of the process come together reminded her of a preacher filled with the Holy Spirit.

For many years as an adult, I worked at doing scientific research, and I felt philosophically at peace. I loved what I did. I was enchanted by the thrill of potential and actual discoveries. I felt that I had found my own comforting worldview, one that I thought was far superior to that of faith, since it had the advantage of being demonstrably true.

During this phase of my life, as I joined the academic scientific community, I loved the magic of creative thought. I loved the passion of the quest for truth and the overwhelming joy at finding answers that will stand as blocks in the immense edifice of knowledge that we human beings have been building for so long.

There was nothing dry or dull in my views of science. Note some of the words I used to describe the scientific process: *beauty*, *magic*, *passion*, *joy*. And although I was an atheist, I began to wonder where all this emotional stuff came from. There was no scientific theory I knew of to explain beauty, magic, passion, joy—or, for that matter, love, humor, music, art, thought, or creativity.

While in college and as a young adult, I began to see spirituality as one manifestation of the human attempt to reach higher in consciousness. I began to learn about consciousness expansion through enhanced mystical awareness. I was no longer worried that spirituality was too irrational or that it couldn't possibly be true, thanks to what I had encountered in the new physics. I didn't see spirituality as something outside of formal inquiry, but even if it was, I had already come to the conclusion that being outside of scientific investigation did not automatically make something unreal.

My mind was now open to new things, new ideas that were all around me. I loved the universal human goal of reaching for more: more enlightenment, more knowledge, more understanding and wisdom, more creativity and happiness. I recently heard the great theologian John Walton talk about this human characteristic, and his words reminded me of these early stirrings of the Spirit in my soul, long before I became a believer.

To be sure, these ideas were part of the culture around me—not the culture of my parents, but the youth culture of the times, which had rejected pure materialism in favor of a general interest in spirituality. Most of the people I knew were experimenting with things like Buddhism, meditation, mind-altering drugs—new ways of experiencing the beauty of natural reality. I didn't go that far (well, mostly

I didn't!), but I found all of it interesting and certainly not worthy of being dismissed out of hand. I did draw the line at ideas that were plainly not only outside of science but also anti-scientific—astrology, pyramids, various forms of magic, UFOs, and later a whole host of conspiracy theories and alternate reality constructions that I could tell were more flaky than spiritual.

I tried transcendental meditation. I looked into Buddhism. I tried a number of things, but nothing really clicked for me. And of course, I was still an atheist. I was seeking to fill the spiritual void in my heart and soul, but I didn't know how or with what. I found I simply could not accept anything on faith, since the whole concept of faith was missing in my worldview.

As my scientific research career developed, I began to feel that it wasn't faith that I had been missing but the thing behind faith: the human need to believe in something, to find a system of thought, a way of seeing the world and everything in it that was comforting, sustaining, satisfying, and indeed joyous. I had found this in science, so science became my method for reaching spiritual goals. The scientific revolution had transformed humankind and the world. Science had shown us how things work, including how we ourselves work. Science had let us see the truth and allowed individual scientists to feel satisfied in their quest and at one with nature.

> Complexity is not only the hallmark of biology but also the basis of a developing scientific revolution.

I expected that that was where I would stay in terms of my search for meaning and understanding. But more questions were arising all the time, and my journey was far from over. As before, the new questions were coming from my scientific milieu, partly from what I was reading about human psychology and consciousness and partly from the work I was doing as a biologist. I became fascinated by complexity. Complexity is not only the hallmark of biology but also the basis of a developing scientific revolution encompassing many fields of study.

Chaos and Complexity Theory

What would you say if I told you that you can use a computer to calculate something and get a completely different result every time you do the calculation? It doesn't seem possible, and yet it happened. In the early days of computing in the 1960s, a scientist named Edward Lorenz reran a simulation for a weather model he had done before, and he got a drastically different result, a weather pattern that didn't resemble the original one at all. How did this happen, when he used the same starting conditions? The second time, he rounded one of the twelve variables from 0.506127 to 0.506, but that wasn't supposed to make more than a trivial difference in the result. This made no sense and seemed to violate everything he knew about mathematics and science. But Lorenz did not check into a mental hospital or retreat into a cave—he kept looking into this phenomenon and came up with a name for it: the butterfly effect. He found that for some unusual iterative equations—equations used to predict how systems behave over time—the results can be so highly dependent on the exact initial conditions that the smallest change in those conditions can have huge consequences: a butterfly flapping its wings in Brazil could set off a tornado in Texas. The whole thing seemed chaotic, and that is the other name for the phenomenon—chaos.

We now know that chaos theory explains many very complex systems with highly interactive components. These include predator-prey relationships, the weather (which is why it will never be scientifically possible to make accurate weather predictions more than a few days into the future), the behavior of the stock market (which is why I am not rich), the way heart muscles work, and even how Christmas tree lights blink on and off.

Fractals

Closely related to chaos theory in terms of describing the enormous complexity of the real world are some very interesting (and beautiful) geometric structures called fractals, discovered by mathematician Benoit Mandelbrot in the 1970s. If we take apart a complex machine, we will eventually get to simple components like gears and bolts. That doesn't happen with a fractal object. The components that make up the fractal object exhibit self-similarity at all scales and are therefore just as complex as the original object—the complexity never ends, no matter how far into the details you go. It is easy to find beautiful examples of geometric fractals online, including the Mandelbrot set.

In the real world, there are very few perfect spheres, rectangles, squares, or straight lines. While we might think of a coast as a line (one dimension), it really isn't. The typical rugged coastline has a dimension that is greater than one but less than two (since a two-dimensional object would be a plane or a terrain). It is a fractal (named after its fractional dimensions), and like the mathematical fractals discovered by Mandelbrot, real-world fractals (sometimes called statistical fractals) are self-similar on many scales.

To visualize a typical fractal in the natural world, think of a rugged coastline like Great Britain's. From twenty thousand feet in the air, you would see a complex, roughly curving shape with bays, inlets, islands, and all kinds of features. Now imagine you descend to two hundred feet in a helicopter. You look down at a particular stretch of that coast, and it looks like it has the same degree of ruggedness as you saw from much higher up. Instead of large bays and inlets, you would now be seeing a portion of one bay, but you would still find features that looked like small bays or inlets. The coast doesn't get any smoother or simpler when you look at a much smaller section. Now, let's say you are on the ground at the water's edge. You will see small coves, channels, and rocks in the water. And it all still looks remarkably like the view from two hundred or twenty thousand feet up in the air.

Self-similarity is also found in clouds, trees, seashells, mountains, and galaxies; in lungs and leaves; and in DNA (discovered by yours truly[1]). Each of these can be expressed as a fractal, with a non-integer dimension.

Fractals and chaos are two aspects of the new science that has been called nonlinear dynamics or complexity theory. It governs heartbeats, sound waves, biological growth, and hundreds of other phenomena. So much of nature seems to fit a fractal model that I have entertained the idea that perhaps all of reality is fractal. This might be one of the greatest scientific discoveries of the computer age.

We now know that our universe is complex far beyond what we used to think. The universe is also fractal, since this complexity is replicated in our own galaxy, solar system, planet, town, house, body, individual cells, and macromolecules within those cells, all the way down to the basic particles and strings that somehow account for all matter and energy.

I think the best published work I have ever done, though it received little attention from the scientific community, is the first demonstration that the coding arrangement of DNA has fractal properties. It was published in the *Journal of Theoretical Biology* in 2007. When I was looking for jobs, I had people ask me, "What is this nonsense about fractals you have here in your CV?" because the work was (way) outside of my actual field. Oh well. It's still my favorite paper.

Is Simplicity a Virtue?

Many scientists believe as an overarching principle that the secrets of nature will all turn out to be understandable by means of beautiful or elegant theories—beautiful and elegant of course meaning simple and precise in science. Einstein was a key proponent, and $E = mc^2$ is one of the best-known examples of such elegance. The structure of DNA is another. But not all solutions are as simple and elegant as Einstein's equations or Newton's laws. Fractals are beautiful, but they are not simple. And they are much better representations of reality than simple geometry.

There is a famous story about the seventeenth-century mathematician Pierre de Fermat, who proposed a simple theorem and claimed to have proved it in an elegant way. His proof was never found, and the best brains of four centuries have failed to replicate it. Then in the 1990s, Fermat's last theorem was finally proven. But, exciting as this was to mathematicians, it was also disappointing because the proof was not at all elegant or simple—it was very long, complicated, and required highly specialized mathematics not known in Fermat's time. It could not have been *Fermat's proof.* Some people even think that Fermat did not actually have a proof, or that he must have got it wrong.

The simple, elegant solutions that scientists have traditionally sought are consistent with a materialistic view of nature. According to this view, everything we want to know can be explained using some basic principles, all of which can be expressed as natural laws. Furthermore, the expectation is that all this knowledge will make sense to us and be consistent with our sense that reality is logical and rational.

I too love the notion of a simple equation that explains a great deal. That is the holy grail of science, and it is a beautiful thing to come across such theoretical marvels. But as I learned about chaos, fractals, complexity, and other modern findings of science, my doubts about pure materialism as the answer to everything grew stronger. The realist in me saw the contradictions, the dead ends and false starts, and concluded that the universe is trying to tell us something, something that we haven't really wanted to hear: "Sorry, guys, the easy stuff is over. Nice work with classical mechanics and momentum and relativity and the Hardy-Weinberg equation and Mendelian inheritance. Great stuff. But now comes the hard part. And you are going to need a larger computer."

Or perhaps we're going to need a whole different approach to how things work and how they came to be.

Fine-Tuning in Cosmology

What I learned about chaos and complexity helped remove my faith in materialism, rationalism, and the other philosophical reasons I started out with for not believing in God. But I also learned something that was more radical—something that actually made me think of a Creator God as a rational idea, or at least as rational as any alternative. This lesson did not make me a theist (that is still to come), but it did suggest a positive *reason to believe* rather than merely taking away *reasons not to believe*. That lesson was the fine-tuning of the cosmological constants.

Most physical laws include arbitrary constants that cannot be derived from theory but can only be measured experimentally—they simply are what they are. I will discuss the unsolvable mystery of the physical constants as an example of a hard limit on what we can discover through science in chapter 8. But for a small subset of these constants, the mystery has even greater significance. These are the cosmological constants—the constants related to how the universe was initially formed.

There are anywhere from six to about twenty of these numbers (depending on different interpretations), and it turns out that their values are highly fortuitous. If they were at all different (in some cases by extremely small differences), our kind of universe couldn't exist, and neither could we.

According to modern physics, there are four forces that underlie all the physical laws of the universe. Two nuclear forces, the strong force and the weak force, govern interactions between particles within the atomic nuclei. At the other end of the scale of object size, interactions between large bodies such as stars, planets, and galaxies are dependent on the third force, gravity. Finally, magnetic and electrical forces between atoms and subatomic particles are different aspects of the fourth, the electromagnetic force.

The great goal of modern physics has been to find a unified theory that can integrate all these forces with each other and show how each force is related by some logical mathematical formulation to all the others. Some progress has been made. The weak force and the electromagnetic force have been shown to be interrelated; at a very early stage in the history of the universe (within the first billionth of a second of the start of the big bang), these two forces were actually one.

The relative strengths of the four forces are determined by specific equations that include some of the cosmological constants. Martin Rees, the distinguished British astronomer, writes in his book *Just Six Numbers: The Deep Forces That Shape the Universe* that these four physical constants (and two others) need to be exactly the values they are, or the universe would be radically different than it is. Changes in any of these constants would make stars, planets, and life impossible.

The fraction of the mass of two hydrogen atoms that is released as energy when they fuse to produce helium is 0.007 (0.7%). That is the source of the heat produced in the sun and in a hydrogen bomb. It is the amount of mass (m) that is converted to energy (E) in the famous Einstein formula $E = mc^2$, and it is a direct measure of the strong nuclear force. If the strong force had a value of 0.006 or less, the universe would consist only of hydrogen—not very conducive to the complexities of life. If the value were greater than 0.008, all the hydrogen would have been fused shortly after the big bang, and there could be no stars, no solar heat—again, no life.

As Stephen Hawking and Leonard Mlodinow put it in their book *The Grand Design*, "Our universe and its laws appear to have a design that both is tailor-made to support us and, if we are to exist, leaves little room for alteration."[2]

There are three possible solutions to the mystery of fine-tuning of the physical constants. One is that there is in fact a good theoretical explanation for these constants, and it will turn out that they had to be exactly what they are. This explanation would most likely be derived from the long-sought "theory of everything," which will connect gravity to quantum physics and answer all questions. However, the theory of everything has so far been elusive. The latest disappointing results from CERN, the largest particle physics laboratory in the world, cast further doubt on these expectations.[3]

Another possibility is that there are or have been an infinite number of universes. We happen to be in this one because this is the only one out of billions or trillions, each with different constants and characteristics, that we could be in. The multiverse theory is favored by many physicists, but it has the problem of being unprovable, since information cannot travel between universes.

The third possible solution, one that is not commonly considered to be within the realm of science, is that God created the universe in a way that allowed stars, planets, and us to exist. While scientists typically reject any supernatural explanations, it must be said that the God hypothesis is not any *more* removed from testing or scientific confirmation than the multiverse. Therefore, a rational thinker is free to choose between two equally plausible and equally non-provable ideas. I now choose God.

Back when I was learning that the world of nature is more mystical and irrational than I had previously believed, I had not yet chosen God. I didn't yet see any of that as pointing me to religion. It was simply showing me that there is more beauty in the complexity of life, mathematical structures, and everything than I had previously known. But this growing awareness of the truth I was learning from science did something important for my slowly awakening soul: it removed a barrier that I had long maintained, a barrier against the possibility of believing in anything that was not grounded in reason. The observer effect and quantum entanglement are not grounded in reason, and yet they are true.

The removal of this obstacle did not lead me directly to faith, but it allowed me to go forward when the time came. But before we get to that point in time, we need to explore in more depth the kind of science that I was not just learning about but doing as my career. And for that we will be diving into the messy, fascinating, and incredibly difficult world of the biological sciences.

Our planet is full of life. The significance of this fact is deep and wonderful. To begin to get an appreciation of the grandeur of life, we must follow, as I did in my scientific career, the path of understanding the amazing revelations of how life works.