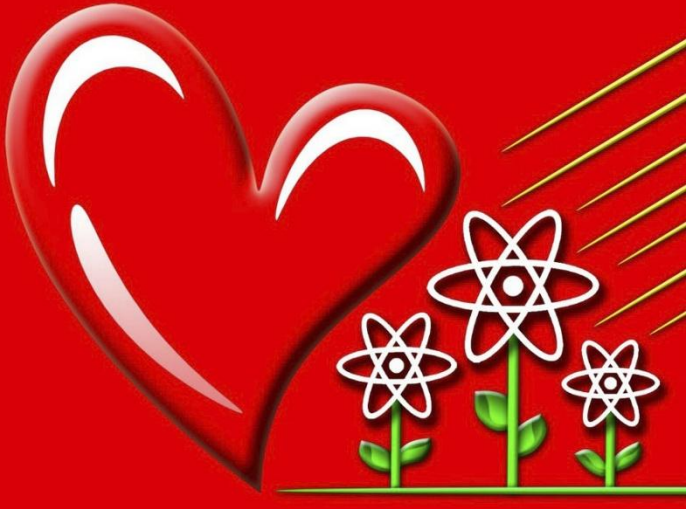
Physics from the Heart



A Quantum Story

Chuck Trunks

Physics from the Heart

Nampa, Idaho

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What if you were lucky enough to come across something that gave you the power to rise above what we're all experiencing in these trying times? And what if you wanted to share it with the rest of the world but realized that your life-changing revelation was understandably complicated and couldn't be offered to the masses through a simple meme, sound bite, or video clip?

Physics from the Heart: A Quantum Story solves this dilemma by packaging its sentient message within a narrative that reads less like a textbook and more like a lighthearted screenplay. Not only will readers find themselves painlessly becoming closet experts on one of the most famous discoveries in all of science, but they'll also be able to connect it to the world around them, including consciousness.

Like any good movie, *Physics from the Heart* is relatable, entertaining, and unpredictable, and it even comes with a surprise ending that explains why this book will leave you feeling both empowered and happy.

From one being to another.

“This work was written independently by the author without the use of generative AI.”

—Chuck Trunks

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Preface

One of my favorite questions that I'm rarely asked is why I wrote a particular book. You'd think that inquiry would be served up more often than not—especially when we all know how committed one must be to publish a book on any given subject. In a world where memes, sound bites, and video clips have replaced books, why would anyone take on such an antiquated and all-consuming endeavor? Why would I commit five years of my life to a regimen of self-education on the subject of quantum mechanics? Why would I dedicate one of those years to creating a dozen art pieces showcasing some of the most fascinating aspects of physics? And why on earth would I continue to put my life on hold for an additional six months to spend every single day putting it all down on paper? The answer, my friend, is so much simpler than the science described in this book. I wrote *Physics from the Heart: A Quantum Story* because I'm compelled to share the astonishing treasure I found at the end of this wonderful five and a half-year journey.

If someone accidentally stumbles upon something he or she knows has the potential to improve the lives of everyone

around them, shouldn't they climb a mountain and shout about it at the top of their lungs? Or should they surround themselves with lawyers and business-minded people to monetize their fortuitous discovery? Maybe, but that's not my style. I'm not talking about a new weight-loss program or a side hustle that'll net you thousands of dollars while you sleep. I'm talking about intrinsic, scientific insight that will awaken a part of you that's typically either underappreciated or largely forgotten. Not only will the knowledge contained in this book change the way you see the world, but I promise you will also feel happier *because* of it.

You will not find another book like this because I searched everywhere for it. Instead, I found bits and pieces of the story I wanted to tell—a story that would tether an amazing phenomenon of quantum mechanics to everyday life, including human consciousness. But the real challenge for me was to create a book that reads more like a relatable and entertaining story than a textbook. Over the years, I have verbalized various portions of this book to friends and strangers while I contemplated writing it. Each time, I was met with bona fide interest, deep engagement, and a genuine thirst to know more. I love being in a position like that, and that's

why I wrote *Physics from the Heart* in such a way that the reader would not only find it easy to enjoy and comprehend, but they could also find themselves in a similar position, sharing this intriguing story with their own family and friends.

I didn't invent or try to replicate any of the experiments mentioned in the following chapters that led to the discovery and application of a branch of physics called quantum mechanics. Instead, I merely reorganized, simplified, and repackaged a few of the most famous principles developed by noted Nobel Prize-winning theoretical physicists to add drama, intrigue, and understanding to a complicated nuance of science that may underpin much of the natural world around us. I offer *Physics of the Heart* in the hopes that it will be a pleasure to read and a reminder that it *is* possible to transcend the soul-crushing fray of a confounding and duplicitous society.

Introduction

I couldn't let it go. Not after learning that molecules, atoms, and subatomic particles can exhibit both particle-like and wave-like properties. *Huh?* That would be like throwing a pebble into the middle of a pond during a quiet Sunday afternoon picnic then correcting your girlfriend after she comments on how it creates such mesmerizing ripples: "No, honey. The ripples *are* the pebble." Not only does this assertion sound like it was dreamt up by an ancient Chinese philosopher who still thought the earth was flat, but it also contradicts everything I learned from classical Newtonian physics.

Wave-particle duality is just one of the many fascinating principles of quantum mechanics used by theoretical physicists to explain the behavior of matter and energy at the subatomic level. But for me, it's even more astonishing to think that these same mind-bending principles may also underpin the very nature of much larger entities, both living and non-living. And if that's true—where quantum mechanics is the straw that stirs the drink of the cosmos—can it also

account for human behaviors, feelings, emotions, thoughts, and ultimately, consciousness?

In *Physics from the Heart: A Quantum Story*, there are no classrooms, textbooks, or quizzes. Instead, it's a journey through a fictitious premise where the settings, science, friends, and narrative are real. If at any time you smile and laugh while reading this book, I'll take credit for that. But if you 'ooh and aah' at any point, I cannot take even one subatomic particle's worth of acclaim. That's why I added a reference section at the end of *Physics from the Heart*—to lay my cards on the table and show the reader who the real scientists and educators are.

My story is divided into four parts. Whereas the first two parts are dedicated to one of the most famous experiments in all of science, the double-slit experiment, Parts III and IV attempt to explain the shocking results of the experiment and show how a quantum mechanics phenomenon can also exist outside the physics lab. However, the real payoff comes in the conclusion, a revelation that first came to me from behind a slow traffic light and soon became my reason for creating this book. And when the last page is consumed, it is then that the reader can

say whether or not *Physics from the Heart* is truly a quantum story.

Part I: Poolside Macrophysics

Whereas astrophysics focuses on stars, planets, galaxies, and other celestial bodies, macrophysics is concerned with bodies of matter large enough to be directly and individually observed and measured. Basically, it's the stuff we can see with our eyes, with or without magnification from telescopes or microscopes. And if the words 'physics' and 'astrophysics' aren't enough of a turnoff to make your eyes glaze over, then the word 'macrophysics' should be more than enough to make them stray from this very sentence in search of anything more exciting. Oh, but you'd be making a big mistake since few phenomena are more compelling than the famous double-slit experiment first conducted in 1801 by British polymath Thomas Young. Not only did it disprove Sir Isaac Newton's century-long theory that light can only be transmitted through particles, but it also set the stage for the birth of modern quantum mechanics in the 1920s and its most famous and astonishing principle: wave-particle duality.

Today, the double-slit experiment is demonstrated all over the world in sophisticated physics labs using complicated, state-of-the-art precision instruments. But that's not where we'll

start in *Physics from the Heart*. Instead, the story opens with a scene that is anything but precise. Bill, a longtime friend from college, and I will spend the entirety of Part I in the overgrown backyard of the dilapidated house of another college friend who just so happens to be a physics professor at our alma mater, North Carolina State University. Although we constantly refer to 'single' and 'double' slits while shooting a BB gun and making waves inside a crumbling in-ground pool, the actual double-slit experiment will be conducted in a physics lab in Part II of this book.

And even though nothing truly astonishing happens in Part I while Bill and I play out entertaining scenes designed to remind you of the classic behaviors of particles and waves in the macrophysics world, the described observations will be invaluable when the double-slit experiment is carried out using an electron gun and a laser in Part II. In the meantime, enjoy the banter between Bill and me in Chapters One and Two. Think of it as a creative refresher course that gives new meaning to the phrase, "See what I'm saying?"

Chapter 1: Large Scale Behavior

The Meetup

“Bill! I’m out back!” I shouted through the open patio slider after hearing my friend of more than forty years open the front door.

As soon as Bill stepped through the slider and joined me on the cracked and crumbling cement patio, he said, “Where the hell are we?”

“Remember the guy I told you about who works in the physics lab back on campus? Anyway, Tom is a friend of mine, and he bought this fixer-upper a month ago. See that empty swimming pool over there? That’s the reason why I asked you to meet me here.”

After a quick scan to his left and right, Bill asked, “Yeah, I remember you mentioning him to me. Is he here?”

“No, he and his wife went down to Myrtle Beach for a couple of weeks. Wouldn’t you if you had this mess to clean up?”

“Chuck, you never cease to come out of left field. What is it this time? A lesson in electromagnetism? A demonstration of the differences between fission and fusion?”

“Nope. Much better than that. Remember when I was talking to you about the wave-particle duality theory of quantum mechanics a few years ago? Well, it’s taken me that long to finally understand it. And guess what? Today’s your lucky day.”

“I knew it . . . Man, you are one weird dude. I guess that’s why I like you. There’s never a dull moment with Chuck! So, how long is this going to take? I have to get back to work.”

“Always the same old Bill . . . the original taskmaster . . . nose to the grindstone. Aren’t you forgetting that everyone works for you?” I said to my highly accomplished college roommate, who was the president of an IT company in North Carolina’s Research Triangle Park.

“You know how it is, Chuck. So, let’s get started. Am I going to leave here knowing how this thing works?”

“Wave-particle duality.”

“Huh?”

“The *thing* is wave-particle duality. That’s what I’m going to show you. But you’ll have to come back tomorrow for the second part. And then I’ll need you to meet me at Tom’s lab on Saturday. He showed me how to fire up his laser.”

“Wow. I guess I’ll have to move my Frisbee golf game to Sunday then, huh? Replied Bill.

“That’s the spirit, buddy! Believe me. You’re going to be blown away. Here. Take this,” I said.

“What’s with the BB gun?” he asked as if he’d never held a weapon before.

“You’ll see once you get into the pool. The first part begins with a little target practice.”

Ready, Aim, Fire!

“This is the worst pool I’ve ever seen. It’s totally flat. There’s absolutely no slope to it,” said the no-nonsense electrical engineer turned executive.

“Astute observation, Einstein. Why do you think Tom is having it filled in with dirt next week?” I teased. “Now use the ladder to climb down, and don’t drop the BB gun.”

“I’ll just use the stairs,” Bill said. “Oh, wait, there aren’t any!”

“Ha-ha . . . Now stand behind that black line. The contraption in front of you is a three-by-twelve-foot section of sheet metal that’s held in place by a wood frame. I also had the guys at Home Depot cut two side-by-side, vertical, twelve-inch slits into the sheet metal. Although one is temporarily covered with a small strip of sheet metal, they’re both wide enough for a BB to easily fit through.”

“Okay.”

“The pool is 32 feet long. You’re ten feet from one end, and

the contraption is two feet from the other end. So, your job is to aim at the open slit and squeeze the trigger. When you do, the BBs will come out in rapid succession, as long as you keep squeezing the trigger. Do it for about a minute, and don't worry about running out of BBs since the magazine is huge. I tried this out earlier, and the BBs left a mark on the pool wall."

"Should I start spraying hellfire now?" asked Bill.

"Hold on, Scarface. Here. Put these safety glasses on and answer this question first," I said while tossing the eyewear down to him. "What do you expect to see on the pool wall after shooting at the slit?"

"I don't know. An image of the Virgin Mary?"

"C'mon, Bill. Be serious. You're holding a weapon of mass destruction, for crying out loud."

"Of course, we'll see marks that correspond to the shape of the slit. Can I light this puppy up now?" he asked with mounting annoyance at the delay.

“Have at it, Bill!”

“Say hello to my little friend!” yelled Bill in a surprisingly decent Cuban accent, channeling his inner Al Pacino from the iconic 1983 film.

After Bill had finished with what looked to be a much-needed emotional release of some kind, we both walked toward the end of the pool with the sheet metal contraption. Bill was still in the pool while I kept my place up above on the cement pool deck, which had weeds growing out of every crack.

“There you have it. Just like I predicted—a shape that matches the twelve-inch vertical slit. It looks like some of the BBs hit the inside edge of the slit and deflected a bit, giving the impact shape a scattered appearance,” remarked Bill while resting the gun over his shoulder like a wannabe outlaw.

“Now who’s the nerd?” I joked. “The marks represent a probability gradient, with most of the BBs hitting along the centerline while the less probable marks are a result of a deflection. See these marks way over here and way over there?

Because they deflected the farthest, those are the least probable marks. Get it?"

"No, professor. Could you go over that again, but much slower this time?" said my friend, who could never resist the urge to be sarcastic.

"Thanks for indulging me, Bill. Now pull that cover off the second slit opening and do the same thing you just did from behind the black line. This time, however, I want you to squeeze the trigger for a minute and a half to ensure enough BBs pass through both openings."

"Got it."

"Oh, and while you're there, push the sheet metal contraption to the left so the BBs hit a clean area on the pool wall," I added.

"Yes, sir!"

"So, what do you think you'll find on the wall after shooting at *both* slits?" I asked.

“I don’t know. The six of clubs? Gees, Chuck. Of course, we’ll see the same result we saw with one open slit, except there will be two similar impact patterns this time. If I didn’t get to shoot this thing, I’d be regretting not eating a seafood salad in the executive dining room right now.”

“Relax, dude. You’re almost done. Okay, go for it, but remember to shoot for about ninety seconds this time.”

“You talking to me? *You* talking to *ME*?”

“Okay, here we go. Now it’s Robert DeNiro from the 1976 movie, *Taxi Driver*,” I mumbled over the sound of BBs being machine-gunned at the two open slits.

After Bill and I inspected the results of shooting at two open slits in the sheet metal, it was confirmed that Bill’s prediction was spot-on.

“Thanks for teaching me nothing, Chuck,” said Bill as he handed me the BB gun while climbing out of the pool.

“It’s all part of my evil plan to waste your time, buddy. Believe me, everything you did here today will come into play in the physics lab on Saturday,” I replied while tossing the end of a nearby garden hose into the pool and opening the water spigot.

“What are you doing now?” asked Bill.

“By the time you come back at the same time tomorrow, the pool will have enough water in it for the second part of the experiment.”

“Great. Am I going to get wet?”

“No. No one is going to get wet. In fact, you should stop at Starbucks before you get here since you’ll be observing a phenomenon that might lull you to sleep,” I replied.

“Great sales pitch, Chuck. Is it going to be like watching paint dry?”

“No. It’ll be much more interesting than that. We’ll be watching water ripples!”

After Bill left, but before the water reached the back wall of the pool, I grabbed a can of black spray paint from the plastic Home Depot bag on the patio and quickly jumped down into the pool. I made a beeline for my friend's first shooting result and painted an L-shaped frame around it, then I did the same thing around the second shooting result. After a few shakes of the can, I went back to the first shooting result and sprayed what looked like the outline of a single, tall camelback hump inside the L-shaped frame. I then did the same thing inside the L-shaped frame of the second shooting result, but instead of one, I sprayed the outline of *two* tall camelback humps.

"Bill's going to hate this," I mumbled to myself while stepping back to admire my artwork. *Poor guy*. Little does he know that a short dissertation on probability diagrams is awaiting his return in less than 24 hours. As straightforward as it is, I would have to explain the graffiti-like diagrams to Bill before starting the second part of the experiment. Hopefully, he'll take my advice and bring caffeine.

Probable Cause

“Chuck!”

“I’m out back!” I shouted through the open patio slider, thinking we were starting the same conversation as the day before.

“Hey, Bill. I was only joking about stopping at Starbucks before you got here. Is one of those for me?” I asked.

“Yep. Just how you like it—black,” he replied while handing me one of the two coffees in his hands.

“Umm . . . That’s not how I like it, but thanks anyway.”

“I don’t have as much time as yesterday, so can we get to it?” he asked.

“Absolutely, Bill. I’m grateful you’re making an effort. Not many people have the patience you have.”

“I thought there’d be more water than this,” remarked Bill while walking toward the pool.

“After about a foot of water, I figured that would be enough to demonstrate what I need to show you today,” I replied.

“What’s with the graffiti on the back wall?”

“That, my friend, is where we’re going to start today. I’m sure you already know this stuff, but it’s important to go through it as a refresher since it sets up the second part of the experiment as well as the results you’ll see in Tom’s lab on Saturday,” I replied. “Can I walk you through the spray-painted diagrams, now?”

“Knock yourself out, Chuck. You were right. I did need to bring caffeine.”

“Okay. Let’s start with the diagram that shows the outline of a single, tall camelback hump. The L-shaped frame around it is simply a graph with the standard x- and y-axes. The two axes provide a coordinate plane for the camelback hump, which in essence is a probability curve. And by probability, I

mean the probability of where the BB would strike on the back wall of the pool if it cleared the open slit. Notice how 90% of the BB impact marks are underneath the fat, middle part of the curve, while the remaining 10% are scattered outside of it. Basically, what this probability curve is saying is that if Bill shot a single BB through the open slit, it would have a 90% chance of making an impact within a predictable area on the pool's back wall. Of the 10% that deflect and impact a location outside of the predicted area, about 10% of those BBs deflect even further away, making them rare instances. See what I'm saying?"

While pretending to be rudely awakened, Bill joked, "Huh? What did you say?"

"Moving on . . . When we look at the diagram around your second shooting result, we pretty much see the same thing as the first diagram, except there are two tall camelback humps—one for each open slit. The rationale is the same here. BBs passing through either slit have a 90% chance of making an impact within predictable areas on the back wall of the pool that correspond to either the first or second slit. The same thing

would be true if there were three, four, or five open slits. Pretty straightforward, huh?"

"Yeah, but what if there were *six* slits? Aha! I got you there, didn't I?"

"Moving on . . . So, in conclusion, there's a distinct and consistent probability pattern that emerges when you fire BBs through any number of open slits, right?"

"Got it, Chuck. So, when does this get interesting?"

"Right after I push you in the pool. Ha-ha . . . Don't worry. I'm about to change things up a bit. Remember, this whole thing *isn't* about particle duality—it's about *wave*-particle duality. Here. Take this and let me explain the second part of this torture . . . er . . . experiment."

"A pool skimmer with a kid-sized soccer ball in the net? Cool! We're going to play a weird game of lacrosse?" blurted Bill as if he had no control over his quick-witted wisecracks.

“Good one, Bill. Now go stand at the end of the pool where you shot from yesterday and don’t put that thing in the water yet.”

“Yes, sir!”

“If we’re going to continue discussing wave-particle duality in Tom’s lab, I need to familiarize you with yet another straightforward scientific concept: wave properties. This part of the experiment won’t leave impact marks on the back wall of the pool, so I’ll need your eagle eyes and sharp mind to see the probability pattern of water waves as opposed to BBs.”

“Got it, Chuck. Keep it rolling. I’m already down to a half cup of coffee.”

“Not to worry . . . You’ll be too busy to finish it anyway.”

Chapter 2: Water Wave Behavior

Making Waves

“I’m so happy. The weather couldn’t be more perfect for this part of the experiment,” I gushed while taking my place near the opposite end of the pool from where Bill was standing. “The diffused light from the hazy cloud cover will make it much easier to see the shadows of the water ripples.”

“Great. Anything that speeds this up will be appreciated. What did you do to the sheet metal contraption?” he asked. “It looks different.”

“That’s actually a different piece of sheet metal because I needed the Home Depot guys to cut out larger vertical slits for this part of the experiment. They’re both 12 inches long, like the BB slits, but now they’re four inches wide and eighteen inches apart. I placed it about ten feet from the back wall and added extra sheet metal panels to either side of it so I could seal the whole thing in place with silicone.”

“It’s not going to tip over, is it?” asked Bill.

“Not a chance,” I replied as I got on my hands and knees to wiggle the top of the contraption to show Bill it wasn’t going anywhere.

“In a minute, I’m going to ask you to lower the pool skimmer so that it’s hovering over the water. To make the ripples, you’ll be tapping the water surface with the bulge of the soccer ball on the underside of the net. You won’t have to do it very hard, but you’ll need a cadence that’s slightly faster than one tap per second. And I’m guessing that I don’t have to tell you to keep the soccer ball in the net. Think you can handle that?” I asked.

“Yeah, but when do I get to catapult it over the neighbor’s house?”

“Ha-ha . . . Wait! Don’t start yet. I need to tape a small piece of sheet metal over one of the slits.”

“Does it matter that the lower halves of the slits are below the surface of the water?” asked Bill.

“Whoa. So, you are paying attention after all,” I replied. “Yes, to some extent, it does matter. Since we want the waves that

you'll be creating to propagate through the openings, the slits must be able to accommodate the wave's highest points (crests) and lowest points (troughs). Having the water level come up to the middle of the slit openings will allow more than enough room for the crests and troughs to pass through. See what I'm saying?"

"Yes, Professor Trunks. Can we get the show on the road?"

"The second slit is covered. So, go for it," I answered.

"Like this?" he asked, acting like the pool skimmer weighed a hundred pounds as he bounced up and down from his knees.

"Ha-ha . . . Relax, dude. You don't have to be so mechanical. And go a little bit faster, too."

While appearing like he was playing a low-hanging bass guitar, Bill asked, "Better?"

"Perfect!" I said, suddenly remembering that Bill was in a high school garage band that covered more than a few hits by The Steve Miller Band. "See how the wave crests are evenly

spaced? That's what we're looking for. Now I'm going to take over for you while you stand between the sheet metal and the other end of the pool. I want you to observe the new wave source emanating from the open slit and how it splashes up against the back of the pool wall."

"Oh my God. Really? When do we start watching grass grow?"

"Ha-ha . . . You're going to live through this, buddy," I replied, taking over Bill's wave-making duties. "Now tell me, what are you seeing?"

"Like you said, there looks to be a new wave source emanating from this side of the open slit. And the wavelength is the same, too."

"Great. What do you mean by 'wavelength?'" I pried.

"One wave cycle or the distance between two crests or two troughs," he deadpanned. "Double E major, remember?"

“A-plus on that one, chief! What about the back of the pool wall?”

Bill retrieved his now-tepid coffee from the pool deck and studied the back wall for more than a few seconds. “The waves emanating from this side of the open slit are curved, like the ones you’re creating with the pool skimmer. And the waves on both sides have the same wavelength, too. As the wave crests move away from the slit opening, they first splash against the pool wall at a position that’s directly across from the slit opening. Then, the rest of the wave crests splash against either side of the initial splash area, but with less of a splash. In fact, the further away from the initial splash area, the less of a splash can be seen when the wave crests hit the back wall.”

After placing the pool skimmer on the deck, I gave Bill a standing ovation, complete with a resounding golf clap. “Bravo, my friend! Bravo!”

“Thanks, Chuck. Now I’m ready for the hard stuff. What’s next? Addition and subtraction?”

“Ha-ha . . . Look at the probability diagram around your first shooting result from yesterday. If we created another diagram around where the waves impacted the back wall of the pool after passing through one slit, it would appear roughly similar to the probability curve of where the fired BBs would strike after passing through one slit. Can you see the similarity in your mind’s eye?”

Bill was mid-sip as he mumbled, “I can.”

“Awesome. Now pull the cover off the second slit and come back over here. I’d like for you to start making waves again with the pool skimmer.”

“Bigger waves with shorter wavelengths this time?” guessed Bill.

“Nope. Same as before,” I replied, shimmying around my friend on the pool deck and catching a whiff of his old-school cologne. “Thanks for taking me back to the eighties, dude.”

“Huh? What do you mean?”

“You couldn’t say goodbye to the Paco Rabanne cologne, could you?” I teased.

“Ha-ha . . . What can I say? The wife likes it,” Bill said as he picked up the pool skimmer, pretending to fling the soccer ball in my direction.

“Take it easy. I still use Irish Spring bar soap, so it’s all good. Now let’s see some waves before we start comparing hair products, Nancy.”

“Ha-ha . . . How’s this?” asked Bill.

“Slow it down a bit and not so hard,” I replied, walking toward the end of the pool with the sheet metal. “That’s it. Perfect. Like that.”

It was hard not to laugh at Bill. But I had to give him credit for indulging my passion for quantum physics. It’s just that his expression of total concentration was tied to tapping a soccer ball-weighted pool skimmer on the surface of a crumbling, barely-filled backyard amenity. “When do I get to see?”

“Hold on. I just want to make sure the waves are propagating through both slits,” I said, nearly kicking what remained of Bill’s coffee into the pool. “Okay . . . I’ll take over the wave-making duties while you observe and report on what you’re seeing between the sheet metal and the back of the pool wall.”

“God . . . I can’t wait to get back to work so I can be the boss.”

“Ha-ha . . . You’re doing good. I just need you to make some excellent observations, like last time. But these next observations are crucial, buddy. Try not to fold under the pressure,” I joked.

“I just wrapped up an $80 million merger at a twenty percent discount. So, I’m pretty sure I got this.”

“Well, thank God we both haven’t forgotten that you’re just a kid from Apex,” I said while taking the skimmer from Bill and replicating the wave frequency. “Okay, Gordon Gekko. Tell me what you’re seeing.”

Watermarked

Bill looked either genuinely captivated by what he was looking at or determined to top his last, spot-on observation. Either way, it was an expression that made me believe he belonged at the top of his company's organizational chart. "Interesting. It's totally different with two open slits."

"Mesmerizing in a way, huh?" I asked.

"It is. The wave frequency on this side matches the wave frequency that you're creating with the pool skimmer, but now there are two identical wave sources emanating from the two slits. As the waves fan out, they start running into each other."

"They interfere with each other," I interrupted.

"Whatever," Bill sighed.

"Actually, it's a pretty big deal. The superposition principle predicts what happens when two waves interfere with each other. Constructive interference occurs when the crests or troughs of one wave meet the crests or troughs of another

wave, resulting in even higher peaks and lower troughs. Conversely, destructive interference is what ensues when the crests of one wave meet the troughs of another wave, or vice versa. In either case, they cancel each other out, resulting in intermittent waveless water if the two wave sources have the same frequency."

"Take a breath, Chuck. It's just water ripples," joked Bill.

"I know. And there's nothing magical about what I just said. Interference is simply a classic, predictable property of waves. Now what's going on against the back wall of the pool?" I asked, maintaining the rhythm of the pool skimmer so Bill could observe the pattern I was hoping he'd see. "You might want to take your time. It's not the easiest thing to see."

I was surprised to see Bill take a knee to get closer to what he was eyeing. Whereas I still bought most of my clothes from Ross Dress for Less, my longtime college friend most likely had tailors flown in from Europe.

"Okay. I think I'm ready!" shouted Bill.

“Go for it!”

“In the first part of the wave experiment, the waves emanating from a single slit splashed against the entire length of the back wall, with the strongest splashes occurring directly across from the slit. In that earlier case, the intensity of the splashes decreased exponentially on either side of the location where the most intense splashing occurred. Basically, the least intense splashes occurred the farthest away from the spot on the back wall that’s directly across from the single slit.”

“Nicely done, William. Keep going!”

While still on one knee and without turning his head to look at me, Bill reported, “Now, with the two slits being open, I’m seeing the same thing . . . but it’s different.”

“How so?” I asked, becoming aware that my shallow breathing matched the cadence of the teetering pool skimmer.

“The first thing I’m noticing is that the initial splash area is directly across from the midpoint between the two slits and

that the splash has a stronger impact against the pool wall when two slits are open as opposed to only one."

"Good eye, Bill. That's the superposition principle at work. Are the most intense splashes happening across from the midpoint between the two slits?"

"Definitely."

"Perfect. That's because that spot on the back of the pool wall is the shortest distance from the original wave source, which is what I'm producing with the pool skimmer. On your side, when the crests of one wave meet the crests of the second wave, they peak even higher, resulting in an amplified wave splash—a clear example of constructive interference. What about the splashes that are happening away from the initial splash area?"

"They diminish in intensity like I observed when there was only one open slit, but they're still bigger than those single-slit waves. I guess that's due to what you said about constructive interference," replied Bill while he shifted uncomfortably from one knee to the other.

“Exactly!”

“But unlike waves propagating from only one open slit, two open slits seem to cause intermittent points along the back of the pool wall where no waves are splashing. It’s like the water is practically flat in those areas. I guess that must be the superposition principle of destructive interference, where the crests of one wave cancel out the troughs of a second wave, or vice versa.”

“Wow. You’ve been holding out on me. Is my old friend a closet physicist? That was fantastic, Bill. Now, before my arms give out, I want you to really look at the entire length of the water line along the pool’s back wall. What you’re looking at is a classic wave interference pattern that’s going to come into play again when we meet at Tom’s lab on campus.”

Bill returned to his feet and began brushing whatever was stuck to his pants. He kept looking at the back wall when he said, “Got it. . . Are we done yet?”

“Almost . . . Keep looking at where I told you to look,” I replied.

“Yes, sir!”

“I want to mentally draw a probability diagram around the interference pattern that you’re currently observing. Imagine that the water line against the back wall is the x-axis and that the y-axis is the line running up the left corner. Based on the frequency and intensity of the waves I’m creating with the pool skimmer on this side of the two open slits, the probability diagram around the interference pattern should have seven camelback humps that begin and end at the x-axis. The largest hump would be at the center of the diagram (indicating the largest wave splashes or intensity), with three descending humps on either side of the center hump (indicating increasingly weaker wave splashes). The dead or flat spots between all seven humps are due to the destructive interference that occurs when crests from one wave are cancelled out by troughs of another wave of the same frequency and intensity. See what I’m saying? Please say yes. I can’t feel my arms anymore!”

“Yes, I do. Does that mean you’ll stop saying ‘constructive’ and ‘destructive’ interference?”

“Ha-ha . . . Nice one, Bill. But guess what? You’re not only done with this part of the experiment you won’t have to return to this backyard jungle ever again,” I announced, dropping the pool skimmer on the pool deck and thinking I wouldn’t need to do bicep curls for the rest of the week.

While stopping the errant soccer ball from rolling into the pool with his wing-tipped oxford, Bill said, “All kidding aside, this was kind of fun. Plus, it reminded me of simpler times. We had fun at State, didn’t we?”

“I couldn’t imagine having a better college experience than what we had,” I replied. “Do you remember where Riddick Hall is on the main campus?”

“Of course I do. I practically lived there during the early 80s.”

“Meet me in the courtyard out front at ten o’clock on Saturday morning, okay? It’s too complicated to explain where Tom’s physics lab is,” I said.

“Lasers, huh?”

“Yes, and instead of a BB gun, you’ll be firing an electron gun. Of course, I’ll understand if you still want to toss Frisbees in the park instead . . .”

“Ha-ha . . . See you then, Chuck.”

Part II: Lab Bench Microphysics

Now that the stage has been set for the real double-slit experiment at the microphysics (or subatomic) level, we should be able to make accurate predictions of what happens when electrons and laser light are directed at first one and then two slits. After all, electrons are just tiny BBs, and laser light is just another type of wave, right? And why wouldn't we feel confident with our predictions? Heck, I could see many of us, including me, going all in on the little white ball landing on red. Who wouldn't place that bet when every number on the roulette wheel looks to be red? If I saw someone bet on black, I wouldn't be able to hold back from saying, "Are you nuts? Your bet is literally saying that the laws of nature change based on the size of things. That's crazy talk! Get this man some black coffee!"

In Part II of Physics from the Heart, the story transitions from the backyard of an in-process home renovation to a collegiate physics lab on the campus of NC State University. Unlike the results seen inside a soon-to-be-demolished pool, the results of the double-slit experiment at the subatomic level are, as Richard Feynman put it, "the central mystery at the heart of

quantum mechanics." This exquisite conundrum, deemed mysterious by a Nobel Prize-winning theoretical physicist, reveals itself to Bill and me in the following chapter. Whereas Chapter Three will put the phenomenon of wave-particle duality on display for the reader, Chapter Four will show you that this nonintuitive nature of matter is consistent throughout the subatomic world.

But with or without amazing results, everyone knows that 'all work and no play' can make a sunny Saturday afternoon spent in a physics lab seem tedious and tiresome. In the next two chapters, you'll be fascinated by what unfolds from the double-slit experiment inside Tom's laboratory, but you'll also join Bill and me as we revisit our old dorm, the student union, and the campus library. Along the way, you'll learn more about our friendship and whether or not soap monsters really exist.

Chapter 3: Duality Revealed

Weird Science

“Well? What do you think? She’s a real beauty, isn’t she?” I asked, presenting the electron gun like I was one of the slinky models on The Price is Right.

“Huh? That’s it? It looks like the front axle from my car if I yanked it out, got rid of the tires on either side, chrome plated the thing, and threw it on top of a lab bench,” replied Bill while settling into a swiveling lab chair that was as tall as a bar stool but with a back support, armrests, and ergonomic foot pegs.

“Yeah, but this isn’t just any old electron gun, dude. You’re looking at the Electro Blaster-Cannon 3000. This baby will burn a hole through the hood of your refurbished Datsun 280Z faster than a can of spilled Coca-Cola,” I teased in my best used car salesman voice. “Yep, this here shiny hunk of space-age technology had only one previous owner before Tom got a hold of it. Rumor has it that it was a little old lady who used the gun to bake cookies in under ten seconds before church on Sundays.”

“That’s right, folks,” added Bill. “Nobody on this side of the Mississippi beats Uncle Chuck’s selection of whatchamacallit thingamajigs!”

“Alright . . . Settle down, buddy. I’ll handle the comic relief around here, okay? So, let me show you how all this is going to work before I fire up the beast.”

Bill hopped off the chair too eagerly, causing it to roll backwards and into an adjacent lab bench. “Oops! Sorry about that. Man, this looks really complicated. Is this supposed to simulate shooting BBs through slits?”

“Okay . . . First of all, take it easy in the lab and don’t touch anything. My lab privileges will be revoked in two seconds if Tom finds anything out of place, okay?”

“Got it, chief,” replied Bill, putting his hands in the front pockets of his jeans and stepping closer to what looked like a pile of spare parts for the space shuttle’s electrical system.

“Whereas the BB gun fired a stream of BBs from about 20 feet away from the back wall of the pool, this electron gun will fire

a beam of electrons from about three feet away. And just like the BBs, some of the electrons will pass through the slits in the barrier, and some won't. And instead of impact marks like we saw on the pool wall, we'll be seeing illumination on an electron detector screen."

"No way!" gushed Bill.

"Yes way. Think of the electrons as tiny, tiny BBs since they, too, are made up of matter. The only difference is their size. So, in essence, we're about to repeat what we did with the BB gun in the pool, except we'll be doing it at the microphysics level, or 'quantum level.' Got it? Any questions?"

"Are we going to shoot electrons through one slit first?"

"Oops . . . My bad," I admitted while pressing the power button on the electron gun's control panel. "I forgot to mention that. Yes, we'll be conducting the experiment through one slit first. Then we'll do it again with two slits, just like we did when you shot the BB gun."

“How does the barrier block the electrons?” asked Bill with his head so close to it that it reminded me of how I must look when eyeballing pre-rolled sushi at the grocery store for freshness.

“I don’t know. Tom lost me after mentioning ‘insulators’ and ‘beta radiation.’”

“Gotcha. How does the electron detector work?”

When the color changed from yellow to green on the power button LED, I announced, “Okay. We’re about ready. Tom said the detector turns the electrons into an electrical current, which allows the attached computer to turn the current into an image on the detector’s screen.”

“Okay then . . . fire away!” Bill shouted.

“Not so fast. You know what I have to ask you, right?”

“I know . . . I know,” Bill mumbled, his gaze fixed on the blank detector screen. “You want to know what I expect to see on the screen as the electrons are shot from the gun. We’ll see the

same impact pattern that was on the back of the pool wall after I shot the BBs through one open slit."

Taking a step backward, I said, "You can do the honors, my friend. Just push and hold down the illuminated green button for about five seconds."

As soon as Bill pushed the button, a low hum could be heard just as a fluorescent green pattern appeared on the electron detector screen. And as Bill had correctly predicted, the shape of the pattern matched the dimensions of the single open slit and was located in an area on the screen where you'd expect to find it—directly behind the slit.

"Okay, Bill. You can stop pressing the button. Check out what's on the screen. You can see that some of the electrons must have ricocheted off the inner edges of the slit because they deflected over here and way over there. It mimics the BB impact marks perfectly. If we were to draw another L-shaped graph around it, the probability curve would almost be identical."

“Okay, okay, I get it. Subatomic particles behave like big particles. Is there anything to eat around here?”

“I love that you just said that,” I replied.

“That I’m hungry?”

“No! I was referring to what you said about electrons behaving like BBs. Let me open the second slit and clear the electron detector screen so we can repeat the experiment with two open slits this time. After that, we can walk over to the student union for some lunch, okay?”

“Sounds good to me. Should I press the button now?” asked Bill, removing his finger from the glowing power button so he could beat me to the punch. “Before you ask, I’ll just tell you now that we’ll see the exact same thing we just saw on the detector screen, except there will be two fluorescent green patterns that will match the shape of the two slits. Oh, and the patterns will be directly behind the two slits as well.”

“Let her rip, William!”

After he fired, I said, “Okay . . . that’ll do it,” backing away from the detector screen so Bill could have a closer look. “Take a gander at this and tell me what you see.”

“What the . . . That’s crazy! That’s an interference pattern like the one we saw when the water ripples went through the two slits in the pool. That’s so weird!” exclaimed my astonished friend.

“Trust me, Bill. It’s going to get even weirder.”

Soap Monster

With the fluorescent interference pattern still illuminated on the electron detector screen like the eerie signature of something sinister, Bill asked, “How can a beam of tiny particles behave like a wave?”

“You tell me. What’s your best guess, buddy?” I prodded.

“Maybe because there are so many electrons in the beam that it’s like a ‘wave of electrons’ going through the two slits like a water ripple?”

“Wow. Excellent observation. You just earned a free lunch, bro.”

With his back turned to me, I heard Bill mumble, “Sweet!” as he retrieved the errant lab chair from across the room.

“Based on what you said about there being a possible ‘wave of electrons,’ I want to repeat what we just did, but I’m going to adjust the gun so it will only shoot one electron at a time. That way, it’ll either prove or disprove your theory, right?”

“Right.”

“Okay. We’re all set. By the time we get back from the student union, there should be enough evidence on the detector screen to put an end to this mystery,” I said while making sure the first few electron blips were registering on the screen.

Bill was already at the door of the lab and describing what kind of hamburger he was going to get when he answered my usual question. “We’re going to see the same pattern we saw when I fired the BBs at two open slits—two vertical bands directly behind the slits.”

“How could that not be the result?” I said reassuringly. “We’re firing only one electron at a time, right?”

“Right!” exclaimed Bill, disappearing into the darkened corridor.

By the time Bill and I reached the sunny brickyard plaza in front of Riddick Hall, we decided to take a detour to where we first came to know each other in the summer of 1982. It had been more than 40 years since either of us took the stairs up to the fourth floor of Metcalf, a 12-story co-ed dormitory for first-year students situated between two similar brick residence halls on the central campus of NC State. It was difficult not to talk over each other while noticing obvious and not-so-obvious changes to the campus landscape as we headed in the direction of the Free Expression Tunnel. I felt grateful for the return of the spring sunshine once we emerged from the chilly, graffiti-covered cement tube that allowed the flow of student foot traffic underneath the railroad tracks.

Since our old dorm wasn’t too far from the tunnel, we were able to see a small crowd of students filing through the front entrance, giving us the perfect opportunity to slip into the

building behind them. Don't mind us, I thought to myself. Just a couple of Wolfpack dads coming to visit their sons. When we weren't able to get into the suite where our adjacent dorm rooms were, I reminded my almost 60-year-old former suitemate of the shenanigans that 'good ol' boy' Ed from Statesville used to pull on our floor.

"Wait a second . . . What? Who's Ed?"

"You don't remember Ed? Oh, that's right. By the time you moved in that first year, Ed had already flunked out. But he remained legendary. Didn't anyone tell you about his soap monster routine?" I asked while we made our way back down the quiet stairwell.

The expression on Bill's face, illuminated by the sunshine beaming through the open door, was a mixture of mild disappointment and anticipatory eagerness when he replied, "No. Nobody said anything. What's a soap monster?"

"I'll put it this way: legend has it that more people have seen Big Foot than the soap monster. And believe me, you'd rather

have Sasquatch crash into your dorm room than Ed after he's polished off a 12-pack."

"Jesus . . . what did he do?" Bill asked as we dodged Frisbees while cutting across the grassy courtyard that separated the Tucker and Owen residence halls.

"Ed would choose some random weekday evening to get all liquored up. Then the 18-year-old, 6-foot-3, 240-pound former defensive tackle would take off all his clothes, jump in the shower, and lather up to a point where you could no longer see his pink, slab-like body. Only his shoulder-length blonde hair, demonized expression, maniacal laugh, and ruddy-complected face gave away the true identity of the infamous soap monster. Wow! I can't believe how much the student center has changed!"

"You cannot leave me hanging, Chuck. How did I not hear this story before?" remarked Bill, who suddenly forgot about his hunger pangs.

"What I'm about to tell you is not folklore since I personally witnessed the aftermath of several soap monster attacks. I can

remember how incredibly hard it was not to laugh while trying to console the beleaguered victims, who could only gawk at the disarray and soapy mess left behind by Ed in less than 30 seconds. Do you want me to finish this story over lunch?"

"Finish it, dammit! This is crazy!"

"In his drunken state, the soap monster, er, Ed, would sneak out of his suite, which was across from ours. Then he'd randomly look for an open dorm room. And if all the doors were closed, he'd simply knock in a way that lulled you into believing that all was right in the world. Was it a suitemate? A friend from class? A girl from upstairs? But the unsuspecting, doe-eyed students would quickly realize that all wasn't right with the world as soon as their faces met Ed's wet, soapy chest. I could imagine the total shock that went through their minds when they heard him yell 'SOAP MONSTER' as he tackled each one, driving them onto their beds or desks like a doomed quarterback. Bedspreads, sheets, pillows, the clothes they were wearing, and whatever was out on their desks would be covered with what used to be slathered on Ed's naked body."

“Oh my God! That’s hilarious! And nobody put a stop to it? Not even the resident advisors?” Bill asked, unfolding his arms and taking the steps up to the student union entrance.

I could see that Bill was still shaking his head as I followed him up the stairs. “As crazy as Ed was, it was impossible not to like him. And the soap monster routine was pretty damn funny. Plus, he always referred to himself in the third person. He’d announce things like, ‘Ol’ Ed is gonna get somethin’ to eat!’ or ‘Ol’ Ed always smells good for the ladies!’ It’s too bad he disappeared after just one semester. You would’ve liked him.”

“I know I would have,” replied Bill as he stepped into the glass and steel building that looked nothing like it did 40 years ago. “Ol’ Bill worked up a mighty big appetite listening to your story! You still buying?”

“Ha-ha . . . Nice one, Bill. Yeah, I’m still buying.”

Camera Shy

When Bill and I returned to the lab, the electron detector screen wasn't as bright as before, but the results were clear.

"Seriously?" Bill asked, squinting into the screen as if the array of dim green bands were a riddle to be solved. "Are you sure that thing fired one electron at a time while we were away?"

"Positive," I replied. "The dimness is due to fewer electrons having hit the screen than when we had the gun at full strength. Although only one electron was fired at a time, they're still fast enough to allow enough blips on the screen to offer a definitive conclusion."

"That's an understatement. It's the same interference pattern we saw when the electron gun was set to full blast. It's not soap monster crazy, but it's still crazy."

"It looks like these subatomic varmints have ol' Bill scratchin' his head!" I drawled in my best country boy accent. "It's nuts, isn't it? These individually shot electrons were either stopped

by the barrier, went through the first slit, or went through the second slit like the BBs did, yet here we have the signature of a wave interference pattern instead of seeing two bands on the detector screen. Unbelievable."

"It's like each electron is interfering with itself as it passes through one of the slits. But how could that even be a possibility if the electrons are like tiny BBs? Are they magically splitting themselves in half?"

"Great guess, Bill," I replied while positioning another instrument the size of a computer webcam near the barrier.

"What's that thing for?" asked Bill.

"It's another electron detector, but this one will flash a red light and make a beeping noise every time an electron passes through the first slit. That way, we'll have a record of the position of any given electron when it passes through the first slit. If the detector doesn't flash or beep and we see a green blip on the detector screen, that will tell us the electron went through the second slit. And if the detector doesn't flash or beep, and—"

"—and—we don't see a green blip on the detector screen, then that'll tell us the electron missed the slits and was stopped by the barrier," interrupted Bill, who was clearly not feigning intrigue.

"Exactly!" I said, as if I were trying to add an exclamation point to the end of my friend's last sentence. "Okay . . . I think we're all set. Go ahead and press the power button on the electron gun. It's still set to automatically fire one electron at a time, so you don't need to hold it down."

"Okay . . . You want to get a coffee on Hillsborough Street while we wait?"

"Not this time, Bill. We need to hang out and watch what shows up on the detector screen. It won't take that long to see what's going on. Tom told me that even though these electrons are traveling at one percent of the speed of light, they're still fast enough to circle the earth in fewer than 20 seconds."

After spending twenty minutes looking at all the cool stuff in Tom's lab like two home improvement addicts perusing

power tools at Home Depot, Bill and I circled back to our ongoing double-slit experiment.

“You knew that was going to happen, didn’t you?” Bill pressed.

“Knew what?” I replied impishly.

“You knew we would be seeing two bands of fluorescent green blips that match the shape of the two slits. In fact, the detector screen looks pretty much like the back of the pool wall after I shot BBs at the two slits. Where did the interference pattern go?”

“You know what’s even weirder?” I asked. “If you listen to the detector monitoring the first slit and watch the detector screen at the same time, you get a sense that the ratio between the electrons going through the first slit, electrons going through the second slit, and electrons being stopped at the barrier is the same ratio we witnessed with the BBs. That can only mean one thing: these subatomic particles have abandoned their unexpected wave-like behavior and reverted

to classic particle-like behavior simply because we started monitoring one of the slits!"

"What a freak show!" Bill gushed. "Let's do it again, but without the detector monitoring the first slit."

"You want me to remove it so you can see if the wave interference pattern comes back?"

Bill shimmied his lab chair closer to the electron detector screen, giving him an even better view from the best seat in the house. "I have to, since you just said that the electrons react differently if they know their position is being recorded."

"You got it, Bill. It's sort of like when I look around to see if anyone is watching me after I've finished putting all the grocery bags in my truck to determine whether or not I'll return the shopping cart to the collection area."

"Ha-ha . . . So, you're one of those guys? Nice moral compass you got there," joked Bill.

After having removed the second detector from the double-slit experiment and observing the same mysterious interference pattern on the screen, I looked at my old friend to get his reaction.

“You might be right, Chuck.”

“Right about what?”

“It’s as if the presence of the second detector determines whether the electrons will behave like particles or waves. It’s like they can ‘see’ the detector as they fly toward it,” replied Bill, putting both hands in the air to signal that he was all out of explanations.

While doing my best to act like I had suddenly come up with an idea that would outsmart the tricky electrons, I hatched a plan in front of Bill. “What if I put the second detector beside the slits again, pretended to set it up so the electrons thought they were going to be monitored again, and then unplugged the thing right before starting up the electron gun?”

“Do we have time for this? I thought we were going to do stuff with a laser too?”

“We’ll have enough time. Plus, this final experiment with the electron gun will tell us if the electrons change their behavior because their positions are actually being recorded at the first slit or if they think their positions are being recorded.”

“You know this is insane, right?” Bill deadpanned, taking his place one last time in front of the electron gun’s control panel. “They’re just tiny BBs—not microscopic spaceships with intelligent life onboard.”

“Fire it up, William!”

When we finished soaking up 20 minutes’ worth of abundant Carolina sunshine while watching baby-faced students from the middle of a landscaped footprint where our math building, Harrelson Hall, used to be, Bill and I headed back to the lab to check on the final results.

“Aww . . . Would you look at that?” I asked in a tone that made it sound like I had come across an angelic, sleeping baby. “The

electrons aren't shy when it comes to allowing us to observe their mysterious wave-like behavior; they just don't want us recording them. I can't say that I blame the little buggers. I wouldn't care either if anyone could see me trying to replicate John Travolta's Saturday Night Fever dance moves, but if someone whipped out a phone, I'd shut that down real quick."

"Ha-ha . . . I totally hear you." Bill's gaze went from the faint interference pattern on the detector screen to the floor, making sure the second detector's power cord wasn't plugged in. "There's no denying it, Chuck. As weird as all this is, you can add me to the army of nerds who need to know what's going on here."

"Don't worry . . . I got this. I spent years studying wave-particle duality. I've read a bunch of books, watched a ton of videos, scanned countless online articles, and befriended a few physicists, like Tom. But before I blow you away by explaining the Copenhagen interpretation of the phenomena we've witnessed here today, help me slide the electron gun over to make room for the laser."

"The what interpretation?"

“The Copenhagen interpretation. Although it’s not the only interpretation, it’s the most widely accepted explanation of the double-slit experiment results. Like I said, you’re going to be blown away.”

“Okay. I’m hooked! Do we have time to grab a coffee at the Starbucks in the library?” asked Bill.

“There’s a Starbucks in there, too? Sure, let’s do it. That’ll give me time to give you a little background on how light fits into what we’re doing today.”

“Sounds good, Professor Trunks,” mumbled Bill while helping to move the electron gun. “You know . . . you probably would’ve been a really good teacher.”

Chapter 4: Subatomic Consistency

Separately Together

The sudden wave of nostalgia almost made me lose my balance as Bill and I rambled down the steps of Riddick Hall toward the library, a place we came to know as home when the world was at our feet—and so much simpler. The momentary quiet between us allowed me to look down and take in the iconic red and white mosaic of the brickyard that was forged into my memory from having traversed it over a thousand times in the 1980s. I looked at my old friend, who must've been feeling like me, when he said, "I was thinking the exact same thing," after I told him that the only thing missing were our 40-pound backpacks stuffed with textbooks.

"Oh my God!" I mumbled to myself. "Is this the D. H. Hill Jr. Library or the Crabtree Valley Mall food court?"

Bill followed me inside after holding the door open. "I know, isn't this crazy?" he asked, standing beside me while we both surveyed the library amenities like wide-eyed time travelers.

“Wow. That little snack bar where I used to buy hot chocolate is now a full-service Starbucks,” I gushed.

“And the arcade room is a student lounge now,” added Bill.

When I looked over to where Bill was pointing, my overflowing heart immediately began to deflate. No fewer than ten girls were slumped on a circular red couch, their shoulders only inches away from their neighbor’s shoulder. Except for their hair and what they were wearing, they could’ve been considered clones of one another. Each one stared blankly into a phone screen while backpacks rested on the floor between their feet. Their expressions, devoid of any clues that would offer a hint of what was on their screens, were a far cry from what you’d expect from a gaggle of young women.

“Hello? Earth to Chuck . . .”

“Huh? Oh, sorry. What did you say?”

“What do you want? I’m buying this time,” Bill asked, holding a black credit card with a noticeable matte finish.

“How about a tall decaf Americano? No . . . wait. Make that a hot chocolate,” I replied, secretly hoping that my preferred choice of beverage when I was eighteen would help me erase what I had just witnessed in the lounge.

Drinks in hand, I suggested that we sit outside on the sun-drenched terrace that didn’t exist when Bill and I were earning our tickets to the ‘corporate’ show. The table Bill chose was perfect because it allowed us to lord over the brickyard like Caesar and Augustus while still being able to smell the flowering dogwood trees in front of nearby Bostian Hall.

“How’s the hot chocolate, Timmy? After this, I’ll get you some cotton candy at the circus,” teased Bill, trying to pull me out of my temporary funk.

“Ha-ha . . . I deserved that,” I admitted. “It’s ten times better than the tepid, watery stuff I’d buy for thirty cents a pop. But at $3.50 (not including tax), it had better be delicious.”

“What’s bugging you?” pried Bill.

“It’s that obvious, huh? I was thinking about irony. To me, quantum mechanics has a duplicitous nature in the same way that electrons can behave as a wave and as a particle at the same time.”

“How so?” asked Bill, keeping his gaze on two idiots having a Frisbee toss despite hundreds of students milling about.

“On one hand, quantum mechanics is so cool and so amazing that it has the ability to bring everyone together—not just the scientific community. But on the other hand, it underpins the very technology that keeps us apart from one another.”

This time, Bill turned his gaze to me when he replied, “I can’t argue with that, Chuck.”

A Perfect Throw

“C’mon, dude!” shouted a voice from a couple of tables over from where Bill and I were sitting. “Take the freakin’ Frisbee game elsewhere!”

“Oh, man! Did you see that? That wild Frisbee throw almost knocked that kid’s lunch out of his hands in mid-bite!” I said to the empty chair that Bill had occupied two seconds earlier.

By the time I spotted Bill, he was scrambling to retrieve the errant Frisbee from underneath one of the few vacant tables. Oh, here we go, I thought to myself as I sat back and watched my old friend, who still looked like he could play Ultimate Frisbee against 20-year-olds. Instead of tossing the Frisbee to the kid who was waving his arms beneath the railing of the terrace, Bill hurled it at his friend. The 50-yard launch came out of Bill’s hand like a clay pigeon from an automatic skeet thrower and banked beautifully into the outstretched hand of a gangly-looking kid wearing flip-flops and holding a drink. Bill admired the loft and trajectory of his perfect throw in the same way a golfer watches his tee shot come to a complete stop despite already knowing it’s in the middle of the fairway.

“So, that’s what five years of competitive disc golf looks like?” I said to Bill as he returned to our table.

“Well, you know . . . Someone has to show these man-boys how to do it,” he joked while looking around to see who else

saw what should be trending on the internet. “Weren’t you going to tell me something about light?”

“Yes. Now that we’re at this point in the experiment, it’s important to give you a brief history of light because it’ll reaffirm what you’ve already witnessed in the lab. Plus, what I’m about to tell you has a lot to do with how the field of quantum mechanics got its start over a hundred years ago.”

“Oh boy. Should I call my wife and tell her I’ll be late for dinner?”

“Relax, dude. Not only will you not be late, you’ll have enough time to sign autographs for your adoring fans,” I teased.

“Then let’s go inside,” Bill suggested.

“We can’t,” I replied.

“Why not?”

“Because the history of light begins with the sun.”

A Brief History of Light

The position of the sun made me feel like the universe was partnering with me. Against all odds, the midafternoon sunlight found its way to a small stand of willow oaks and red maples to the left of where Bill and I were sitting on the library terrace. They were lit up beautifully and stood out against the red brick buildings directly behind them.

“Prior to Thomas Young proving that light was a wave as opposed to particles through his groundbreaking invention of the double-slit experiment in 1801, the scientific world could not disprove Isaac Newton’s earlier theory that light was made up of tiny particles, or “corpuscles,” as he referred to them in a published paper in 1704. And why would they want to? Isaac freaking Newton was a celebrated rock star back then, as he is now. But the British polymath, Young, came up with a clever plan using sunlight, a pinhole, a mirror, a double-slit barrier, and a screen.”

“Keep going. I’m following what you’re saying,” said Bill when I stopped to take a sip of my still-warm hot chocolate.

“Since candlelight and lanterns couldn’t provide a coherent light source, Young harnessed a single beam of sunlight from a pinhole in a window shutter and redirected it toward a double-slit barrier using a mirror. By doing so, he created two identical light beams from a single light source that produced the classic, telltale signature of wave behavior on a screen behind the two slits. He produced the unmistakable interference pattern, proving that the two coherent light beams emanating from the other side of the barrier were indeed interfering with one another.”

The legs of Bill’s chair made a loud screech when he adjusted himself away from the direct sunlight. “That’s pretty cool,” he said as soon as he was resettled.

“I guess so,” I admitted. “But it would take another hundred years and legendary theoretical physicists such as Michael Faraday, James Clerk Maxwell, Heinrich Hertz, Max Planck, and Albert Einstein’s Nobel Prize-winning explanation of the photoelectric effect to unequivocally distinguish light as both a wave and a particle at the same time.”

“Like the electrons in Tom’s lab?” Bill asked.

“Exactly!” I replied, pushing my chair back and recreating the same annoying sound from a moment earlier. “Yes, but instead of shooting electrons from an electron gun, we’ll be shooting photons from a laser.”

“Then, let’s do it!”

Without a nod or verbal confirmation, we both got to our feet at the same time. After hearing an audible groan from Bill when we pushed our chairs back under the table, I asked, “What’s wrong?”

“Can you believe it? I think I tweaked my shoulder when I threw that Frisbee.”

Déjà Vu All Over Again

As soon as I opened the door and stepped into Tom’s physics lab for the third time that day, it finally dawned on me what the room smelled like. Since they say that our sense of smell conjures up the most vivid of memories, I wasn’t surprised when I was magically transported back in time to the den of my family home in suburban Philadelphia. As a ten-year-old

in 1975, I was rarely without a baseball in my hands. So, when it fell and skittered behind the television during a Sunday evening airing of The Wonderful World of Disney, my family was more annoyed than startled. Never in a million years would I think that this mundane, forgettable memory would be brought up or retold in a book about physics. But the distinct acrid fumes from heated cathode ray tubes, inorganic chemicals, and dust wafting out the back of a 100-pound TV are apparently unforgettable.

Although my first step back into the lab solved the mystery of what Tom's workspace smelled like, my second step made me think of Dr. Frankenstein's laboratory. In the darkened room, the apparatus of the double-slit experiment lay on top of the cold lab bench like the doctor's infamous monster. Different colored lights blinked while beeping noises sounded off randomly around the room, giving me the impression that it was alive. If Bill hadn't flipped on the lights behind me, I probably would've imagined the beast rising stiffly from its prone position to tell me, "Me both monster and wave of monster."

"Ready for the last leg of the experiment, William?"

“I am. Let’s do it.”

“Okay, here’s the plan. We’ll run the laser light beam at full strength through one slit first, then two slits. After that, we’ll do it again, except we’ll run the laser low enough to emit only one photon at a time, like we did with the electron gun. Then, we’ll bring out the second detector again and monitor the first slit to see if the photons behave differently than the electrons when it comes to observing them versus recording their positions.”

“Gotcha. Ready when you are,” chimed Bill, appearing eager to see something larger than a laser pointer fire a beam of intense red light.

“Hold on. Almost there. Remember when we used the pool skimmer to create the original wave source in the pool? And remember how important it was to make sure we were striking the water surface with the same intensity while maintaining the cadence? By having all that dialed in, it allowed us to see a distinct interference pattern against the back of the pool wall. In essence, we were creating a coherent wave source, which in turn created two coherent wave sources at the double-slit

barrier, which then produced a clear interference pattern. In the lab, this here Death Ray 5000 will take care of all that for us since it produces monochromatic or single-wavelength light."

"Holy crap! My ears are bleeding! Can we get started already?"

I felt bad for putting the kibosh on my friend's enthusiasm when he saw the single red band and the equally red interference pattern on the turned-off electron detector screen, the results of having passed laser light through one slit and then two, respectively.

"Dude, relax. At this point, you're seeing the exact same results we saw with the water ripples. I'll admit that the red laser light makes it seem like big science, but the wave nature of light is nothing new. Visible light is just one of the many types of radiation that carry both electric and magnetic fields while traveling through space as waves. Collectively, radio waves, microwaves, visible light, ultraviolet light, x-rays, and gamma rays make up the electromagnetic spectrum."

“Now I think I want to kill myself,” joked my friend with the same dramatic timing as a Bravo TV housewife.

“Ha-ha . . . I’ve missed your sense of humor, bro. Okay, let’s dial down the laser, which, in essence, is like dimming the lights in your dining room with a dimmer switch. But instead of a romantic dinner for two, we’ll be enjoying a one-photon-at-a-time ambiance to replicate what we did with the electron gun.”

“Speaking of dinner . . . can we move this along?”

Bill and I were able to move quickly through the rest of the experiment because it was the perfect example of what New York Yankee legend Yogi Berra once quipped: “It’s like déjà vu all over again.” The photons, fired one at a time, exactly mimicked how the electrons behaved when fired individually, including the nuance of allowing their duplicitous nature to be observed but not recorded.

“See that?” I asked. “The double-slit experiment demonstrates that both electrons and photons exhibit wave-particle duality. In fact, all atomic and subatomic entities exhibit this

phenomenon. Isn't it amazing that a tiny, tiny BB in the form of an electron can morph into a wave and that a wave of light can behave like a particle in the form of a photon?"

"I'm serious when I say that I'm impressed with how passionate you are about all this stuff, Chuck. And I know there's more that you want to cover. Plus, I do have a bunch of questions for you. Do you think it would be okay if we picked this up again tomorrow? Could you meet me at the New Hope Disc Golf Course in Apex tomorrow morning at ten?"

"I know exactly where that is," I replied, shutting down the laser and unplugging the detector screen. "But I don't own a single Frisbee."

Bill was already heading for the door while looking at his watch when he said, "Don't worry, I've got you covered."

And just like that, my college friend from a faraway era disappeared into the abyss of the shadowy hallway. I stood motionless in the lab and listened to his footsteps get quieter and quieter on the polished floor. A pause ensued, followed by

the sound of a heavy door being pushed open. After making sure everything was where it was supposed to be, I flipped the lights off while mentally saying goodnight to the return of Frankenstein's monster. Oddly, by the time the late afternoon sun was lighting up my face outside of Riddick Hall, I wasn't thinking about my days as a college student on the campus of NC State University. I was thinking about my little league team in suburban Philadelphia.

Part III: Quantum Revelation

For some reason, I like writing introductions to the chapters that make up each part of the books I write. It doesn't make sense because I'm not the type to flip the pages or press fast forward to steal a glimpse at what's to come. Heck, I'll even put my hands over my ears and start making sounds similar to Jim Carrey's character in Dumb and Dumber if I even think someone is going to blow the ending of a book or movie before I've had a chance to experience it. And as for those TV shows that reveal the secrets behind many of the most popular magic tricks, I'd rather skip them and be content with the implausible spectacle of showmanship. But after writing Chapters Five and Six of Physics from the Heart, I feel I must prepare the reader for what will appear to be an even greater illusion than the mystifying results of the double-slit experiment.

I'm no sorcerer. However, I did manage to organize the revelations that explain the duplicitous behavior of quantum particles around the most obvious questions. And the answers will astound you—but not in the same way as being shown that the magician's assistant was scrunched up in the upper section of the box during the saw-the-lady-in-half trick.

Instead, you will soon learn that the secrets behind wave-particle duality are even more astonishing than the lab experiment itself. In quantum mechanics, there are no secret compartments, trap doors, gimmicks, or sleights of hand. And without a single trick up their sleeves, Nobel Prize-winning theoretical physicists explain the dichotomous nature of matter through concepts such as the Copenhagen interpretation, de Broglie's matter waves, Heisenberg's uncertainty principle, and informational isolation.

I invite you to learn about these transcendent concepts with Bill and me along the American Tobacco Trail in Apex, North Carolina. Remember, this is supposed to be an entertaining story that just so happens to reveal an amazing principle of quantum mechanics—not a textbook. So, be prepared for a bit of history, coherent explanations, and clever analogies that level the playing field and make learning feel more like discovery. Pack a lunch, put on comfortable walking shoes, and turn off your phone. Our journey includes fresh air, inspired imagination, spirited dialogue, and a shared interest in the world we live in.

Chapter 5: Duality Explained

Plan B

“Chuck! Over here!” shouted Bill from across the crowded parking lot.

From beside my truck, I could see my friend standing behind the open trunk of an all-black Mercedes AMG GT. Despite not knowing anything about cars, let alone expensive ones, I had actually heard of this particular model. Strangely, I remembered that the price tag was around $300,000, that it had more than 700 horsepower, and that it could go from zero to 60 in just over three seconds flat. Unfortunately, Bill’s car was one of many at the popular 18-hole disc golf course, making the fussy old man inside me bristle at the thought of having to share the park with a bunch of hungover 30-year-old hipsters. Why aren’t these people in church? Even the temperature was adding to my sour mood. The partly sunny skies and projected high of almost 70 degrees had lulled me into wearing shorts and only a short-sleeved t-shirt under my bright yellow windbreaker, yet the temperature was still below 50 when I sauntered toward Bill.

“I’d say this is a step up from your old Datsun 280Z,” I gushed through chattering teeth.

Bill stopped fiddling with what I assumed was his disc bag and turned away from the trunk when he heard me. “Bad news, dude.”

“What? Don’t tell me. They need you in Geneva, right?”

“No, my shoulder is still messed up from yesterday. I can’t believe it. I came out here a little early to see if I could work it out, but it still hurts like hell. I’m sorry, buddy.”

Although I felt bad for my friend, I was more disappointed that I wouldn’t have the chance to school him on his home turf. Little did he know I had spent five summers throwing Frisbees on practically every beach between Malibu and Huntington Beach in Southern California after graduation.

“That sucks. How about an easy hike instead?” I asked.

“I’d be up for it, but we’ll just be in the way of the other players,” replied Bill.

“Yeah, that’s what I was thinking,” I said sarcastically. “Lucky for us, the American Tobacco Trail starts right across the road. You’ve got a disc bag, and I’ve got a backpack. Let’s pack the food and drinks we brought and go for it. What do you say?”

“Okay . . . let’s do it!”

“Great!” I responded while starting to jog back to my truck. “Be ready in five minutes!”

“Gees . . . What’s the rush? You really can’t wait to talk about the results of the double-slit experiment, can you?”

“Yes, that’s true. But if I don’t start moving soon, I’m going to freaking freeze to death!”

Quantum States

After we crossed New Hope Church Road and entered a small clearing, Bill asked, “Is this the trailhead?”

“No, not yet. It’s about a quarter mile up ahead. There’s a big kiosk with a map and really nice bathrooms. From there, the trail winds through a series of s-turns before connecting with the rail trail.”

“So, I take it you’ve been here before.”

“Many times,” I replied.

“What’s a rail trail?”

“It’s a trail that results from removing the old tracks of a retired railroad line. The American Tobacco Trail is one of the nicest in the country,” I explained, keeping my gaze on the ground in front of me to avoid adding a sprained ankle to Bill’s shoulder injury.

For the next fifteen minutes or so, Bill and I walked in relative silence, both of us enjoying the rare sounds of nature—and its simplicity. The midmorning cacophony was a mixture of sounds from hardworking Downy woodpeckers, swaying longleaf pines, and crunching gravel beneath our feet.

“So, remember when I mentioned the Copenhagen interpretation after we finished using the electron gun?” I asked, breaking the silence with the same subtlety as the Kool-Aid Man crashing through drywall.

“Oh, boy . . . Here we go,” replied Bill, matching my pace perfectly. “I’m just kidding. Let’s hear it.”

“Even though the results of the double-slit experiment are undeniable, there are a dozen different interpretations of what we observed yesterday—and the Copenhagen interpretation is just one of them. I like it because most of today’s quantum physicists consider this interpretation to be correct. Plus, a couple of Nobel Prize-winning theoretical physicists, Niels Bohr and Werner Heisenberg, not only proposed this interpretation, but they were largely responsible for founding the field of quantum mechanics in the mid-1920s. In it, they say that a quantum particle (like an electron or a photon) does not exist in one quantum state or another but in all of its possible states at the same time.”

“What do you mean by ‘quantum state?’”

“It’s a mathematical entity that provides a probability distribution for the outcomes of each possible measurement of a quantum particle. I know . . . It’s a mouthful, but it’s a really important term to understand. Imagine if you were to punt a soccer ball from the front door of your house. Factoring in who’s punting it, we could feasibly come up with all the possible locations where the soccer ball could come to a stop. You might launch it 40 yards, where it bounces and rolls to a stop in the gutter in front of the Martins’ house. Maybe a line-drive punt causes the ball to get wedged under a car in the driveway of the house directly across the street. Or, you sort of miss it, making the ball go off the side of your foot and causing it to skitter underneath the bushes in your front yard. Are you with me so far?”

“I am. Keep going. Just keep in mind I was a defensive end and the punter on my high school football team,” replied Bill, who seemed to be enjoying the analogy.

“Got it. I’m glad to see you’ve let go of the glory days,” I joked sarcastically. “We would also know where the soccer ball wouldn’t come to a stop. It wouldn’t stop somewhere behind your house. It wouldn’t stop a half-mile away. And it certainly

wouldn't stop underneath a potted plant or a trash can. So, we know that the possible stopping locations for the punted soccer ball are finite—even if there are a million possible stopping locations. See what I'm saying?"

"Go on," mumbled Bill while digging for one of the orange Gatorade bottles in his disc bag.

"But because some regions within the area of all possible stopping places are more likely to experience stopped soccer balls than others, we could create a probability distribution of punted soccer balls based on Bill's athleticism and punting experience. And do you know what that probability distribution would look like? It would look like the probability diagram I spray painted around the impact marks in the pool after the BBs were fired at the barrier with one open slit."

As Bill and I got closer to the Beaver Creek footbridge, we naturally made a beeline for the sunny section of railing. The opening between the beech and river birch trees gave us a wonderful view of the numerous longleaf pines rising out of the swampy water. They reminded me of cypress trees in the bayou country of Louisiana. With a heavy mist rising off the

still water, the whole scene looked both prehistoric and primordial.

“Pretty awesome, huh?”

“The view or the Copenhagen interpretation?” asked Bill.

“Both,” I replied.

“You did a great job of explaining what a quantum state is, so I totally get what the Copenhagen interpretation is saying.”

“Are you kidding me? We haven’t even reached the halfway point! The good news is that we’re going to keep talking about soccer balls.”

A Quantum Punt

“How far does this trail go?” asked Bill, who showed no signs of tiredness or a bum shoulder.

“All the way to Durham,” I replied, pointing to a modest mile marker in the distance.

“Can you read that from here?” I asked.

“It says 21.5.”

“Okay,” I said while reaching for a fig Newton. “The whole trail is 23.5 miles, so we’ve gone about two miles so far—not counting the distance from where our cars are parked to the trailhead. Now let’s get back to talking about the Copenhagen interpretation and quantum states, shall we?”

“Go for it, professor. But can you spare a couple of fig Newtons? I don’t think I’ve had one since I was eight.”

“Ha-ha . . . Sure, buddy. Knock yourself out,” I replied, handing Bill two of the energy-packed cookies from a sandwich baggie. “Remember, the Copenhagen interpretation says that a quantum particle can exist in all of its possible states at the same time and that a quantum state provides a probability distribution for the outcomes of each possible measurement of a quantum particle. So far, you know what a quantum particle is and what is meant by a probability distribution. Now I need to talk to you about how an electron

can exist everywhere at once and what happens when that electron is detected."

"I thought you were going to continue with the soccer ball analogy."

"Relax. I haven't forgotten. Imagine that you're about to punt the soccer ball, and just as your foot makes contact, the ball disappears—only to reappear after it comes to a complete stop. While we wait for the ball to become visible again, we can speculate as to where it will most likely turn up by looking at the probability distribution. Both of us agree that it'll most likely show up at the bottom of the depression in Mr. Hatfield's front yard, which is 35 yards away. After 15 seconds or so, we see that the ball stopped next to Mrs. Vandenberg's mailbox, 25 yards away. Does that mean the probability distribution is wrong? Of course not. That would be like saying the roulette ball should've landed on the red number seven. What's important is that the soccer ball stopped within what was possible in the probability distribution. In other words, the ball stopped somewhere where we expected it to stop. In this case, the soccer ball simply stopped in an area

that we deemed likely—as opposed to most likely. Are you still with me?"

"I am. But other than the trajectory of the soccer ball being hidden from us, this sounds like my Statistics 101 class back in 1982. What's the point of hiding the path of the ball?"

"I was hoping you'd say that, Bill."

"What I just described was the double-slit experiment in Tom's lab—but without the two-slit barrier. Your leg is the electron gun, the soccer ball is the electron, and the reappearing soccer ball is the blip on the detector screen. According to the Copenhagen interpretation, the electron particle becomes an invisible wave of potential as soon as it is shot from the gun. This unrealized potential resides inside a sphere of what's possible within a probability distribution. And, since it's a wave of unrealized potential, it has no physical reality. However, this changes once the wave is detected by a measuring device. Detection, like what we observed on Tom's electron detector screen, causes the wave function to collapse from a realm of possibility into a singular reality. And in our case, the waves of each electron collapsed

back into a particle that registered as a fluorescent green blip on the detector screen."

"Okay. I'm following you, but why share a soccer ball analogy that doesn't include a double-slit barrier like the ones we used in the pool and in Tom's lab?" asked Bill.

Stopping in my tracks for a more theatrical effect, I replied, "It's like you peeked at my notes or something. Another great question, dude! And the perfect lead-in to the most mind-blowing aspects of the Copenhagen interpretation."

Shh . . . It's a Secret

"That's perfect," I said, nodding toward the distance.

"What's perfect?" asked Bill while shifting his disc bag from one shoulder to the other.

"That bench up there. How about if we eat our lunch there and then start heading back? I'm thinking that'll put us just over six miles by the time we get back to the cars. How's your shoulder feeling?"

“I could go further, but it’s probably best not to push it. It doesn’t hurt if I shrug or swing it. But as soon as I lift it, it hurts like a mother. God! Why did I have to be such a hotdog yesterday?”

For an early afternoon on a beautiful Sunday, the American Tobacco Trail seemed to belong to just Bill and me. The quiet brought on a sense of calm and an appreciation for what was still right with the world. Even if we forged ahead another five miles, the trail wouldn’t have changed very much. To some, the flat, 20-foot-wide path would be too monotonous, maybe even boring. But to me, the dark woods of the forest contrasted nicely against the cement-colored gravel. The tree-lined straightaways made me wonder what it would’ve been like to march as a victorious Roman soldier in a column of thousands. Thunderous chariots would—”

“Man, you really do eat like a third grader,” teased Bill, interrupting my momentary mind trip.

“What do you mean?” I asked.

I could see Bill's eyes scanning my peanut butter sandwich, eight apple slices, six Oreo cookies, a box of raisins, and two juice boxes. When he finished, he asked, "What? No chips?"

Peeling back the top of my sandwich, I deadpanned, "They're in here."

"Ha-ha . . . I knew it! You're a theoretical quantum physicist wannabe who still eats the lunch his mom packed for him in elementary school. You do realize that you're pretty weird, right?"

"Then I'm in good company because Einstein never wore socks."

"Ha-ha . . . Speaking of socks, weren't you going to blow mine off with more of the Copenhagen interpretation?"

"Yes, I'm going to. Just don't be drinking anything when I deliver the goods. I wouldn't want you to choke or anything. The reason there was a double-slit apparatus in the pool was to show the expected Newtonian behavior of particles and waves. Plus, it would give you an idea of what to expect—and

not expect—in the lab at the quantum level. To me, what's ingenious about the double-slit experiment is that the two-slit barrier reduces the realm of possible electron locations seen on the detector screen into a more manageable probability distribution. And it not only proves that the electron traverses along every possible path between the electron gun and the detector screen at the exact same time, but it also demonstrates that these paths actually interfere with each other! Okay, here's where you start choking on your granola bar."

"That doesn't make sense."

"Which part?"

"How can possible paths interfere with each other?"

"Only one way, my friend. It interferes with itself. This offers proof that the electron is everywhere at once until its wave of potential collapses in response to being detected. When the electron gun fires a single electron at the detector screen without a two-slit barrier, the electron is a wave of potential that interferes with itself until its wave collapses back into a particle after having been detected by the detector screen. By

installing a two-slit barrier between the electron gun and the detector screen, we're able to prove that the electron is passing through both slits at the same time and interfering with itself before collapsing back into a particle as it's detected by the detector screen. Pretty amazing, huh?"

"I'll say," replied Bill. "But how can individually-fired electrons create a collective interference pattern that looks eerily similar to the interference pattern that appears after billions of electrons are fired at the same time?"

"Okay. See if you can wrap your head around this. It doesn't matter if a zillion electrons are fired at the double-slit barrier every second or if one electron is fired every hour—the same concise, symmetrical interference pattern will reveal itself on the detector screen. The only difference is the time it will take until we can definitively see the pattern. It's not like the electrons huddle up and make a plan. The electron gun is a precision instrument that can fire any number of electrons at the exact same energy level, giving each electron the same wavelength. This means that each electron obeys the same probability distribution, resulting in an interference pattern of intermittent fluorescent green areas on the detector screen."

“I’m still following you, but why would the signature pattern of particle behavior replace the interference pattern on the detector screen when you set up the second electron detector at the first slit?”

“That’s because the electron’s wave potential collapsed back into a particle after being detected in the opening of the first slit. Then it continued on and hit the detector screen as a particle—sort of like a BB hitting the back of the pool wall directly behind the slit it went through.”

“But what about the electrons that weren’t detected at the second slit? Why did those electrons behave like particles when they didn’t interact with the second electron detector?”

“Love the question, William,” I replied, gathering my trash and stuffing it into my backpack. “Oh, but the electrons going through the second slit were detected—indirectly. If you recall, the second detector flashed and beeped as an electron passed through the first slit, followed by a blip appearing on the detector screen. If the detector didn’t react, we knew that the electron wasn’t passing through the first slit. And there you have it.”

“What? And that makes an electron wave passing through the second slit collapse into a particle as well? Because we know where it isn’t? And that’s why we saw classic particle behavior at both slits?”

“Yes. I don’t think I could have said it any better than that,” I replied, standing up to start heading back toward the trailhead. “The universe doesn’t mind if you observe quantum particles within a quantum system. But it will collapse the wave-particle duality of a quantum particle if it knows that you know anything about where it is or where it’s going.”

Chapter 6: Preserving Randomness

Matter Waves

Even though Bill and I were retracing our steps back to the trailhead, the path looked different—even brighter than before. The early afternoon sun, when it wasn't playing hide and seek with the clouds, had chased the midmorning shadows back into the forest, qualifying the scene as background imagery for inspiring quotes. On either side of the gravel trail, a dense forest of tall, skinny trees made me feel both protected and insignificant. While Bill was quiet with his thoughts, I was busy imagining myself as a flea living on the back of an enormous hairy beast and wondering if I should climb one of these hairs to see where we were headed. How could I find out what kind of animal I was living on top of? Would I go deaf if it howled? What if some other animal . . .

"Chuck . . . Earth to Chuck. Do you read me? Over."

"Huh? What did you say?"

Sometime during my mental hiatus, Bill had pulled out his phone and had it pressed against his ear when he said, “I was trying to tell you that I need to check in with Ines.”

“Oh, sure. Of course,” I replied, immediately stepping away as if I had accidentally barged into a private conversation.

Even after almost 35 years of marriage, I could tell that Bill was still in love with his wife. The softness of his expression and tone of voice while he spoke to her took me back to the campus library, where my 20-year-old friend had introduced me to his new girlfriend, Ines. I can still remember Bill asking me, “Where are you going?” after I tried studying with them at the same table. The next day, I would end up telling my lovesick friend that Ines was a fox and that I couldn’t concentrate sitting between a ravenous wolf and a pork chop.

“Ines wants you to come over for dinner tomorrow. None of the boys are visiting, so it’ll be a quiet evening. What do you say?” Bill asked while stuffing his phone into a disc bag compartment specifically designed for electronics.

“That would be great. Don’t you work tomorrow?”

“No. Since I’m flying to San Francisco on Tuesday for a few days to deal with that new acquisition, I decided to make it a three-day weekend.”

“As long as it’s Stove Top stuffing, I’m staying!” I joked, confident that Bill would get the arcane reference.

“I’m seeing a pattern here, Chuck. Not only do you pack a lunch from the 1970s, your jokes are that old, too.”

“Ha-ha . . . If we don’t get back to my lecture on the mysteries of the universe, this might spill over to tomorrow evening’s dinner conversation,” I teasingly threatened.

“There’s more?”

“Did you know that physicists started trying to duplicate the results of the double-slit experiment using matter larger than subatomic particles? After successful results with a single atom, they began experimenting with particles that were composed of 10 atoms, then 100, and even 1,000. Within the last few years, particles as large as 2,000 atoms were observed to have a wave-particle duality in the double-slit experiment.”

“So, it sounds like as laboratory equipment gets more and more sophisticated, physicists can observe wave-particle duality in larger and larger particles of matter, yes?” asked Bill, looking at the gravel path in front of him as if he saw what he was asking about.

“Yes, but only up to a certain point. According to Louis de Broglie’s 1929 Nobel Prize-winning theory that all matter can act as waves, smaller objects have longer wavelengths, while larger objects have shorter wavelengths. Of course, I’m oversimplifying the work of de Broglie because momentum affects the wavelength of matter as well. But for the purposes of this talk, it’s easier to remember that size matters when it comes to observing wave-particle duality.”

“So, does a BB have a wave?”

“Yes.”

“Does the BB gun have a wave, too?”

“Ha-ha . . . Yes! How much bigger do you think a BB is compared to a grain of salt? Ten times? Fifty times? Don’t

answer because a single grain of salt contains a million trillion atoms, pairing an equal number of sodium atoms with the same number of chloride atoms. Now imagine multiplying that number by 10 or 50 to get the total number of atoms in a single BB! If a particle made up of only 2,000 atoms produced a wavelength that was so short that it was barely detectable in the double-slit experiment, can you imagine how short the wavelength would be for a single BB?"

"I'm still trying to wrap my head around a million trillion," admitted Bill.

"I hear you. When I was first learning about all this, I kept expecting to read that there was a dividing line that separated the matter that could be a wave from the matter that couldn't. In the end, physicists were able to prove that all matter has what de Broglie called 'matter waves.' Once I understood that wave-particle duality could be observed in one sodium chloride molecule but not in an entire grain of salt, I finally understood that this phenomenon simply couldn't be observed or measured within everyday objects."

"So, am I a wave?" asked Bill.

“Well, you’re made up of bones and tissue that are made up of complex molecules, right? And complex molecules are made up of atoms that are made up of subatomic particles, right? So, you tell me. Is Bill both a man and a man of potential?”

“Then I guess that makes me a wave. But I’m not so sure Ines would agree with that. To be honest, I’ve never thought of connecting quantum mechanics to philosophy.”

“It truly does, Bill. But it also relates to spirituality.”

I attributed the sudden surge in my friend’s pace to his interest in learning more about the far reaches of quantum mechanics rather than an urgency to get back to the parking lot.

“Really? Spirituality, as well? I can’t wait to hear this. You’re not going to talk about the healing powers of crystals, are you?”

“Ha-ha . . . No, but let’s table this until tomorrow evening, okay? I’d like to include Ines in the discussion and hear what she has to say about it. In the meantime, I need to introduce you to another principle of quantum mechanics. It’s called the

Heisenberg uncertainty principle, and it offers an explanation as to why the universe plays its cards so close to its chest and why these subatomic buggers are so damn camera shy."

Conjugate Variables

Although the temperature had risen to the predicted high, I kept my windbreaker on since the morning breeze was still holding steady in the midafternoon. So, this is what the train conductors saw when they were hauling tobacco from regional farms to Durham from 1920 to the mid-70s, I thought to myself. Besides being at the controls of a powerful locomotive engine, they had a front-row seat to soak in the view of the Caribbean-like lushness of the Carolina countryside. The weather was spectacular, but I knew deep down that the dreaded humidity, which would feel like a donkey kick to the chest while standing in a steam bath, was only a month away.

"So, what's the Heisenberg uncertainty principle all about?" asked Bill.

Grateful to replace thoughts of impending abject perspiration with imagery of quantum particles, I replied, "In a nutshell, it

basically says that the more we know about a particle's position, the less we know about its momentum, and vice versa."

"Okay, but could you remind me what momentum is?"

"Sure. Momentum is calculated by multiplying the mass of a particle by its velocity, where velocity is defined as the directional speed of the particle. I know, even the motion of something sounds overly complicated in quantum physics."

"Ha-ha . . . It's the same thing in telecommunications," added Bill.

"So, in the case of the uncertainty principle, position and momentum are just another pair of conjugate variables that surround us in our daily existence. Take direction, for instance. If you were traveling northwest at a perfect 45-degree angle, you would be gaining as much of a northerly position as a westerly position. But for every degree you turn the steering wheel to the left or right, you gain more position in one direction at the expense of gaining position in the other direction. There's simply no way around it."

“Okay. That’s pretty straightforward to understand. How would that work with position and momentum?”

“Because uncertainty in position and momentum is so small in our everyday world, it’s not something we concern ourselves with or even think about. But in the quantum world, it’s a very big deal. Let me share this great analogy that I learned from watching British theoretical physicist, author, and broadcaster Jim Khalili as he explained the uncertainty principle. Imagine if I emailed two files to you. One is a photo taken just after the cue ball hits a collection of billiard balls to start the game. The other is a short movie clip of the cue ball doing the same thing. Both files were captured from the same overhead angle and have the exact same file size of 200 kilobytes. When you open the photo, you’re able to zoom in on any billiard ball and gain a high degree of certainty as to where each ball is located on the table. However, that same high degree of certainty wouldn’t apply to knowing where the balls are headed in the photo. Conversely, when you open the clip of the billiard break, you first notice the grainy, pixilated quality of the video, but you’re still able to gain a high degree of certainty about where the balls are headed in the clip. However, since position and momentum are conjugate variables, you’re not

able to apply that same high degree of certainty to the location of the balls in the low-resolution video file. See what I'm saying? Is that a great analogy or what?"

"It is," replied Bill. "But how does Heisenberg's uncertainty principle relate to the double-slit experiment?"

"Perfect question at the perfect time, William. Oh, and by the way, 'question' and 'time' are not conjugate variables."

"But Chuck's knowledge of quantum physics and his social life are," quipped Bill, dishing it as well as he could take it.

"Ha-ha . . . Let's talk about detection, shall we? Imagine if a highway patrol officer pulled you over and told you that you were driving 20 miles per hour over the speed limit. In order for the officer to have determined your speed, his radar gun had to emit an electromagnetic radio wave that struck your vehicle before reflecting back to the radar gun's receiver. What's interesting about this is that the photons of the radio waves didn't knock your vehicle over to the next lane or over the guard rail."

“Huh?”

“You see, Bill. The speeding ticket analogy explains what’s going on at the quantum level. When I set up the second detector to flash and beep when it detected an electron passing through the first slit, I inadvertently bombarded the electron with high-energy photons, thus altering both its position and momentum. Detection, at the quantum level, is not a passive process of observation but rather an interaction that causes the wave function to collapse from the realm of what’s possible into an exact measurement. By gaining more awareness about the position of an electron through the use of a second detector device, we lost awareness about the electron’s momentum, as indicated when we watched the intricate interference pattern dissolve into a simpler pattern of two fluorescent bands.”

“That’s incredible!”

“What’s incredible?” I asked.

“I actually get what you said,” beamed Bill, stopping to take off his sweatshirt.

“Remember, it goes both ways. While we watched the interference pattern reveal itself on the detector screen from either a slew of electrons being shot all at once or one at a time at the two slits, we basically had a pretty good idea of the electron’s momentum, which, if you recall, includes its speed and direction. Conversely, we had no idea where the electron was until it showed up on the detector screen as part of the interference pattern. The uncertainty principle underlies the Copenhagen interpretation that explains the results of the double-slit experiment. Not only does Werner Heisenberg’s famous equation tell us that it’s impossible to know the position and momentum of a quantum particle with absolute certainty at the same time, but it also explains why we cannot know (with absolute certainty) the wave and particle behavior of a quantum particle simultaneously.”

“I have to say, Chuck. You’re really good at explaining all this. I mean it when I say that I’m grateful you’re sharing this with me.”

“Relax . . . We’re just a couple of conjugate variables enjoying a Sunday hike on a glorious spring day.”

“You had to ruin the moment by making it weird again, didn’t you?”

“Ha-ha . . . Sorry, but I couldn’t resist using the term ‘conjugate variables’ as a punchline of sorts. I guess I can finally cross that off my bucket list!”

Informational Isolation

I was glad when Bill and I finally veered off the rail trail, returning to the series of twists and turns that told us the trailhead was a little less than a mile away. The serpentine trail was narrower, making my connection with the forest feel more personal, even intimate. I had never read a book from The Lord of the Rings series, yet I felt like a hobbit walking through Middle Earth. And as a three-foot-tall troll-like humanoid, the sound of unseen squirrels bounding across dry leaves made me worry about the not-so-nice hobbits who lived in this part of the forest.

“You do like to space out, don’t you?” asked Bill. “What were you thinking about this time?”

“Well, if you must know, I was thinking of another reason why we’re able to observe wave behavior in quantum particles but not in everyday objects like BBs, baseballs, or tennis balls.”

“Okay, let’s hear it,” said Bill, who, at some point, stuffed his sweatshirt between his shoulder and the strap of his disc bag. Seeing me look at his makeshift shoulder pad prompted him to add, “It’s a disc bag, not a backpack.”

“Only a mile to go, buddy. In the meantime, I want to talk to you about informationally isolated objects. Remember when I was telling you about de Broglie’s ‘matter waves?’ And that matter larger than a couple thousand atoms, let alone a BB, was too big for its wavelength to be observed or even measured? Well, as it turns out, the universe is pretty stingy with information. But that shouldn’t come as a surprise. After all, I did say that the universe will collapse the wave function of a quantum particle if it knows that you know anything about where it is or where it’s going. And we witnessed that very phenomenon each time the electron’s position was detected by the detector screen or by the second detector device. So, in retrospect, we know what will make a wave collapse, but do we know what keeps a wave from collapsing?”

“Umm . . . By not trying to detect the location of the electron, duh,” replied Bill, in a voice that sounded more like Lenny in John Steinbeck’s Of Mice and Men than the president of a Fortune 500 company.

“Yes, of course. But the answer is ‘information isolation.’ Thanks to a terrific video from physics educator Alvin Ash, I learned that the wave behavior of a quantum particle is a statistical envelope or probability distribution of all the possible paths (or quantum states) that the particle could take within a quantum system. If the which-path information is revealed in any way, regardless whether it is observed or not, the universe will collapse the wave function of the particle.”

“But why would the wave collapse if the electron wasn't observed, detected, or measured?” asked Bill, his tone bordering between weariness and exasperation.

“Because . . . drum roll, please . . . The universe is its own observer! How crazy is that? Don’t answer because I want to reiterate the point by adding something we discussed earlier. Even though the unrealized paths can interfere with one

another, the quantum particle must remain informationally isolated. Now that's crazy on top of crazy, right?"

"I'm pretty sure I'm going to need a couple of beers and a few Frasier reruns to turn my brain off when I get home."

"Okay, maybe this will help. Imagine you're an electron that just got shot out of an electron gun. Immediately, an undeniable sense of possibility overwhelms you. With your wave-particle duplicity unfolding and spreading out before you, you suddenly feel everywhere at once. But instead of freaking out, your wave function is calming, almost serene. You wonder if this is what it feels like to drop acid as you fly through both slits at the same time, like a bolt of lightning in a maze of mirrors. A surge of invincibility reminds you that, as an informationally isolated quantum particle, nothing can stand in the way of your nothingness. For once in your misunderstood life as an electron, you realize anything is possible and that the universe is . . . WHAM! You slam into a detector screen, collapsing all that could've been into a singular reality that obeys a statistical probability distribution. Reduced to a tiny fluorescent blip on the detector screen, your dream is shattered. Solace replaces disappointment when you

realize that you're one of thousands, maybe millions, of blips that collectively form the mosaic of the interference pattern."

"Nicely done, Chuck. But this sounds like it has more to do with your personal life than the flight of an electron. Either that or you've actually done hallucinogenic drugs before."

"Ha-ha . . . No. I made that up just now. I promise you, my imagination is 100% drug-free," I replied, grateful I didn't tell my friend that I had been daydreaming about Roman soldiers, train conductors, fleas, and hobbits.

A Record of Interaction

"I still don't get how the electron was informationally isolated in your story," admitted Bill.

"As a wave function of possibilities governed by a probability distribution, the electron interacts with nothing. It doesn't encounter or affect atoms or other subatomic particles, like photons. Again, it doesn't interact with anything. If it did, the universe would collapse the wave—even if we didn't observe, measure, or record the electron. Information isolation doesn't

mean invisibility. It means that the subatomic particle cannot interact with anything else in the universe without creating a record of that interaction. So, another reason why we can't see or detect matter waves in everyday objects is that it would be virtually impossible to informationally isolate something like a tennis ball."

"Hey, I need to use the restroom," announced Bill, setting his disc bag down on the cement pad underneath the trailhead kiosk that showcased an end-to-end map of the American Tobacco Trail.

When he came back out, I was glad to hear Bill ask, "So, why would it be impossible to informationally isolate a tennis ball?"

"See how far we went?" I blurted while keeping my finger on the spot where Bill and I had lunch.

Bill began transferring trash from his disc bag to the large receptacle between the two unisex bathroom doors. "Was it six miles like you thought?"

“More like six and a half after we get back to the parking lot across the road,” I replied, waiting for Bill to finish so I could get rid of my trash as well.

The two of us walked side by side to begin the last quarter mile. Unlike the morning hours, when the gate to the trailhead was locked, the air quality was no longer pristine and crystal clear. A smoky pall lingered over the trail and had the same color and consistency as chalk dust from classroom erasers. To avoid the occasional passing car, we moved as far to the right as possible without having to bushwhack through the thick foliage that lined either side of the gravel road.

“In order to informationally isolate a moving tennis ball, you would have to remove all the air and light around it. Any interaction with a single atom, molecule, or photon would result in a record being made that divulges which-path information.”

“Okay, now I get it,” said Bill.

“Wait! There’s more,” I interrupted. “You’re not done isolating the tennis ball. Besides making sure the ball remains

in a pitch-black vacuum, you would need to remove any gravitational effects and freeze it to a temperature of absolute zero so it wouldn't emit photons of its own through something called 'black body radiation.' You see, gravity would affect nearby atoms, thus creating a record in the universe of the tennis ball's path. And photons radiating from the ball could be analyzed to determine the which-path information. In either case, the universe will collapse the wave function. Do you still get it?"

Bill was looking both ways along New Hope Church Road when he signaled that it was safe to cross. He replied, "It reminds me of the butterfly effect, where something as innocuous as the flap of a butterfly's wings can lead to a typhoon in a much larger, complex system."

"I see where you're going with that. But I think the whole notion of wave-particle duality is less about cause and effect and more about maintaining absolute secrecy around future outcomes. Although physicists have a long way to go before completely understanding the enigmatic world of quantum mechanics, they've learned how to harness the power of what they do know. First and foremost, the modern computing

world as we know it through laptops, tablets, and cell phones wouldn't exist without quantum physics, which made it possible to build microscopic transistors out of semiconductor materials like silicon. Telecommunications and the internet would still be as slow as molasses in January without the laser technology behind fiber optics. Even the calculated arrival time on your phone's GPS function is courtesy of quantum mechanics. If it weren't for the precision and agreement between the atomic clocks of several satellites, you might not have been on time today."

"I hate to burst your bubble, Chuck, but I already knew all that," said Bill, sounding apologetic for stealing the thunder of what he thought was my big climactic moment.

To seize the opportunity to act the part of a frustrated lecturer, I responded, "Well, umm . . . did you know quantum physics is responsible for fluorescent lighting?"

"Sort of, yeah."

"Okay, well, how about the fact that only quantum physics can explain why your toaster works?"

“Huh? What?”

“Did you know that wave-particle duality is the main reason why we have to do yard work?”

“Wait. Slow down.”

“And did you know that quantum mechanics can explain global warming? That it’s enmeshed in philosophy? And did you ever think that the behavior of quantum particles and spirituality are two sides of the same coin?” I continued, tossing my backpack into the backseat of my truck.

“Whoa . . . Settle down, buddy. Ines will be interested in the philosophy and spirituality stuff,” offered Bill, backpedaling toward his car while looking at his watch.

“Awesome hike, Bill. Hey, what time should I come by tomorrow?”

With his back to me as he fished for his car keys from the disc bag, he replied, “Let’s do six o’clock.”

“Okay. That sounds good!” I shouted. “Hey, one more thing, Bill.”

“Yeah?”

“Will you be interested in the philosophy and spirituality stuff, too?” I asked.

“Absolutely. But first, I’ll want to know how my toaster works!”

“Ha-ha . . . See you tomorrow, Bill.”

Part IV: A Quantum World

Now that you'll be the smartest person at the dinner table should the topic of wave-particle duality come up in between passing the potatoes and telling the kids to sit up straight, wouldn't it be even better if you could further pique the curiosity of your friends and family by explaining how this amazing phenomenon of quantum mechanics isn't just relegated to controlled experiments in physics labs? Of course you would—but not in a self-important, know-it-all sort of way—especially since neither of us figured out any of this on our own. Like you, I learned about the famous double-slit experiment before discovering that the astonishing results may underpin the very fabric of our daily lives.

Over the next two chapters, I'll invite you to join me for dinner and conversation in Bill's backyard, but instead of sagging fences, a cracked pool, and a garden of weeds three feet tall like we saw at Tom's fixer upper, you'll meet his lovely wife Ines and feel like you're dining outside the halfway house at Augusta National. Oddly, our spirited discussion opens with dialogue around a simple kitchen appliance before transitioning to more intellectual yet equally random-

sounding topics like computers, photosynthesis, the human brain, and the elementary make-up of our physical selves. Then, as if perfectly timed and orchestrated in a Hollywood studio, our discourse finds its way toward human consciousness just as night falls in earnest.

Oh, and somewhere in the mix, Bill gets into a fight.

Chapter 7: Every Day Quantum

Prestonwood

"Now this is a nice community," I gushed loud enough to hear myself over the addictive lilt of Morrissey's "Suedehead." Although I hadn't been back to Cary in almost 35 years, the town's original charm was still recognizable despite years of mounting affluence. When I turned right onto Creek Park Drive from Davis Drive, a song came on the radio that made me think of the time when Bill and I drove to Fort Lauderdale for Spring Break.

I had first heard Don Henley's "Boys of Summer" while standing at the end of the pier in Pompano Beach. It was during the last sunset of our last day in Florida. Bill had walked back to the food concessions, giving me enough time to appreciate and savor the beauty and weight of that moment. I'm glad I did, because to this very day, I find myself back on that pier whenever I hear the seagulls in that iconic song.

My, my, my . . . isn't this swanky? I thought, painfully aware of my muddy, 10-year-old truck. The little community of

Preston was anything but little. Founded in the early 1990s by the SAS Corporation as a place its employees could call home when the budding software giant relocated its headquarters from a rinky-dink building near the campus of NC State University to a sprawling business park in Cary, it slowly became a highly sought-after zip code. If Preston was the face of a tennis racquet, Bill and Ines lived in the middle of its sweet spot—the prestigious Prestonwood Country Club, a lavish, full-service resort with three manicured 18-hole golf courses. My mind naturally compared the pleasant twists and meandering turns of the wide, pristine avenues to the crumbling, grid-like farm roads that surrounded my neighborhood back in Nampa, Idaho.

I took my time driving. Going slow enough to appreciate each of the stately mansions along either side of Creek Park Drive, I was likely attracting the attention of security personnel. When the Spin Doctors came on the radio, I mumbled, "Okay, this is getting weird." Not only was "Two Princes" the favorite song of a former girlfriend, but it reminded me of when we'd drive down to Beverly Hills from Thousand Oaks in Southern California to gawk at the estates of Hollywood royalty. Snapping me out of the impromptu trip down memory lane,

my GPS squawked, “Turn right onto Old Pros Lane.” Obediently, I made the turn and found what should’ve been Donald and Melania’s house at the end of a private cul-de-sac.

Bill and Ines’ place looked to be situated on the 50-yard line of its own football field. Instead of a wide-open expanse, it was expertly contoured with well-appointed landscaping, stone footpaths, and sophisticated water features—aesthetics that could easily rival the front lawns of the Royal Family. When Bill told me to park under the carport, I wasn’t expecting it to look like the valet parking area of the Four Seasons Resort in Palm Beach, Florida. Thank God I had that oil leak fixed last month. As I approached the front entrance, I strangely remembered the ending of every episode of The Beverly Hillbillies, when the Clampetts would stand outside the front entrance of their Bel-Air mansion, waving goodbye to the viewing audience. “Wow! The facade of Bill’s house is even more impressive than Jed’s make-believe home,” I said quietly, anticipating the sound of the doorbell. But before I could press it, Bill opened the door.

“Right on time, buddy. Welcome to my humble abode.”

“Gorgeous place, Bill. I love it! Where’s Ines?”

“She’s still getting ready. Hey, I’ve got a surprise for you.”

“Oh, yeah? What’s that?” I asked.

“I made sure we picked up some Pabst Blue Ribbon for you.”

“Oh my God! You remembered!”

“Hey, let’s grab one and go out back, okay?” suggested Bill.

While Bill was retrieving the beers from the other side of an industrial-looking glass refrigerator door, I noticed two things. The first was that the full-service kitchen we were standing in wasn’t even the house’s main kitchen. The second was that an eight-slice stainless steel toaster had been pulled forward from the back of an adjacent counter. The junior detective work was nothing to brag about since I could see the main kitchen through an archway as well as the telltale crumbs that typically accumulated underneath toasters.

“Umm . . . Were you actually trying to see how your toaster works?” I asked, just as Bill handed me a cold one.

“Ha-ha . . . No. I think everyone knows how a toaster works. But you said there was a connection to quantum mechanics. So, I pulled it out so I wouldn’t forget to ask you about it.”

“Good. I like that you did that. One minor point: I didn't say quantum mechanics would explain how it works. I said it would explain why it works. Physicists, in the late 1800s, were—”

“Hold that thought,” interrupted Bill. “Let’s take this outside. You don’t need the toaster, right?”

“Ha-ha . . . No. There won’t be a need for any props,” I replied, pushing the clunky kitchen appliance back over the crumbs.

I followed Bill as he walked through the pantry archway and into the main kitchen. From there, he turned to the right and proceeded through an already open set of French doors. On the other side, the backyard landscaping looked both whimsical and engineered. Instantly, I was faced with every

shade of green—some of which I had only seen around castles in Ireland.

“So, what do you think?” asked Bill.

“I think I want to build my tiny house over there,” I replied, pointing with the hand that was holding the unopened PBR. “That would be the perfect spot, in between those two crepe myrtle trees.”

“Umm . . . I don’t think you could afford the property taxes,” joked Bill.

“Who said anything about money? I’d be trading my Frisbee throwing skills and quantum physics knowledge,” I teased while opening my beer and letting the sound of it serve as an exclamation point.

While leading us toward patio furniture that I’d be proud to put in my living room, Bill laughed and said, “I already know you can throw, so we’ll conduct the lease agreement around your knowledge of quantum physics. You can start by telling me about this toaster thing.”

“My pleasure. But first, I have one quick question.”

“What’s that?”

“Does your Wi-Fi signal extend to the crepe myrtles?”

L’eggo My Eggo

With more than an hour of sunlight left in the Carolina sky, I settled into a spot on the couch directly across from Bill. From my vantage point, I could see over a large water hazard and onto a fairway lined with majestic pine trees. Since few golfers were out playing at this hour of the evening, the job of disrupting the quiet stillness fell to the easily spooked mallard ducks gathered on the far-left bank of the pond. I took a sip of my beer and thought it was considerate of my friend to allow me this stunning view while he faced the entrance to the terrace.

“Alright, where was I? Oh yes, now I remember. In the late 1800s, physicists figured out that any object, whether it’s composed of metal, wood, glass, or anything else, will glow the same color when heated to the same temperature. The

incandescent red glow of the nickel-chromium heating element inside your toaster has a temperature of around 1,200 degrees Fahrenheit. And the flame of a candle is even hotter, with the orange and yellow colors registering temperatures of 1,700 and 2,000 degrees, respectively. If you were looking into a campfire while roasting hotdogs, you'd see the 2,400-degree white color closest to the burning logs. But if you prefer to boil your Ball Park Franks on a stove, the blue color of the burning natural gas has a temperature of around 2,800 degrees."

"Okay. I'm following you," said Bill in a tone that told me he wanted to hear more.

"If we're talking about visible light, then we're also talking about the middle of the electromagnetic spectrum, where the colors we can see fall between the longer wavelengths of red and the shorter wavelengths of violet. Light with wavelengths longer than a dark red shade is invisible to our eye and falls into the categories of either infrared, microwave, or radio. Conversely, light with wavelengths shorter than the color of dark violet is also invisible to us and can be classified as either ultraviolet, x-ray, or gamma. For example, right now I'm

emitting invisible infrared light waves at a temperature of around 98 degrees Fahrenheit."

"Gotcha, Mr. Warmth. What happened to the toaster story?"

"Ha-ha . . . Okay, I hear you. I'm almost there. So, back then, physicists theorized that if they kept increasing the temperature of an object, it would eventually start to emit ultraviolet, x-ray, and gamma light. But when their Newtonian theoretical math didn't match what was being observed and measured, they called it 'the ultraviolet catastrophe.' It wasn't until German physicist Max Planck discovered that all light is emitted in chunks, packets, or quanta in 1905 that physicists were able to revise the math to correctly predict the behavior of thermal radiation."

"And the toaster fits in where?"

"And the toaster was invented the following year, in 1906. Oh, and besides being a timeless kitchen appliance, Planck's discovery also opened the door for Einstein to coin the term 'photon' for quantized particles of light, influenced Niels

Bohr's description of electron energy levels, and created an entire new branch of physics called quantum mechanics."

"Hmm . . . I have to admit that's pretty interesting," offered Bill while turning toward what looked like yet another kitchen on the opposite side of the terrace.

"I know. It sort of gives new meaning to Kellogg's 'L'eggo my Eggo,' right?"

"Dang it!"

"Dang it? What's that for?" I asked.

"I was sure you'd say something more along the lines of 'toaster strudel,'" replied Bill, emphasizing the last two words in a decent-sounding German accent.

"Ha-ha . . . Don't try and run with the big dogs," I joked.

"Whatever. Help me get this grill going."

“You mean, help me get this thermal radiation device going,” I said, sounding as if I were teaching remedial English to a class of unwashed heathens.

“Ha-ha . . . I guess I should’ve seen that one coming.”

Quantum Computing

Ines’ timing couldn’t have been worse, as Bill was just about to reveal the secrets behind his grilled bone-in chicken breasts.

“Hey, Chuck! Sorry about that. It’s definitely not fashionable when the host shows up late, right?”

Like her husband, Ines looked like she wouldn’t know the guilty pleasure of KFC’s mashed potatoes and gravy or the breadsticks at Olive Garden. Both of them looked like they hadn’t missed a day of exercise since being awarded their degrees in engineering in the mid-1980s. Even after having given birth to three boys and pushing 60 years of age, Ines looked fit enough to run what Bill and I had walked a day earlier on the American Tobacco Trail. Unlike my college classmates, who were aging gracefully into older versions of

Ted Danson from Cheers and Julia Louis-Dreyfus from Seinfeld, I was thinking I'd most likely end up looking like the old balloon salesman from the movie Up.

"Don't think twice about it, Ines," I said, giving her a brief hug and noticing a hint of tea tree oil coming from her shoulder-length brown hair. "It's great to see you again."

"It was kind of a crazy day, even though I worked from home."

"Bill told me you're a patent attorney for a biotech company," I added, briefly turning my attention back to the grill to see if any of Bill's secrets could be visually pilfered.

Ines smiled at her husband before taking a seat at the bar behind the crackling grill. "To make matters worse, it was taking forever to upload a trio of patent applications in preparation for a crucial meeting with the FDA on Thursday."

"Not to worry, Ines. Quantum computers are not that far away."

“Oh, here we go,” chimed Bill, as if he were a runner in the starting blocks just waiting for me to utter the word ‘quantum.’

“Don’t listen to him, Chuck,” said Ines, taking a sip from Bill’s beer on the bar. “I’ve been steadily hearing more and more about quantum computers, but I have no idea how they work. What’s the difference between what we’re using today and what these quantum computers will bring in the future?”

Doing my best to channel my inner Renee Zellweger’s character from the movie Jerry Maguire, I leaned toward her and said, “You had me at hello.”

“Ha-ha . . . same old, Chuck. He’s always working in a famous movie quote whenever he can,” joked Ines.

“What can I say? I love talking about this stuff,” I admitted. “So, back in the mid-1960s, a guy named Gordon Moore claimed that the number of transistors on microchips would double approximately every two years—and that’s exactly what happened. Referred to as Moore’s Law, he predicted that computers would become smaller in size and that computational speeds would become increasingly faster and

significantly more efficient over time. Take my iPhone, for example. It has more than ten billion transistors and is 100,000 times more powerful than the NASA computers that put men on the moon more than 50 years ago! But guess what? That's coming to an end. Today's transistors are already just about as small as they can possibly be—between five and 10 nanometers. Not only are the laws of physics putting an end to Moore's Law, but the phenomenon of quantum tunneling will have an impact as well."

"What's quantum tunneling?" asked Bill from behind the noisy grill.

"I'm not exactly sure, but I know it's about subatomic particles like electrons passing through barriers, causing all kinds of problems for our current arithmetic machines."

"Wait. What? Arithmetic machines?" asked Ines, who somehow managed to pour herself a glass of white wine without me noticing.

"Well, that's all they really are," I replied. "Transistors are simply the physical embodiment of bits, where a bit is a binary

number that's either on or off, true or false, a one or a zero. An enormous number of bits is necessary to compute complex problems like figuring out the most efficient route between multiple points or cracking encrypted passwords. And the more bits, the longer the processing time. Believe it or not, some encryption algorithms would take millions, maybe billions, of years to crack, but a quantum computer could theoretically do it in a matter of minutes or hours."

Both Ines and I jumped when the grill lid slammed down. "Sorry about that," Bill offered apologetically. "That thing just slipped out of my hand."

"Come over and join us," said Ines, patting the bar stool seat next to her.

"Yeah, have a seat and let me finish telling you what I learned about quantum computers," I added, as if I were seven years old and would burst if I didn't get to spill the beans about how caterpillars turn into butterflies.

Bill sat down next to his wife with an audible sigh. "Can you wrap it up in 10 minutes?" he asked.

“Sure, but why the rush?”

“The chicken will be perfectly done by then.”

“No problem,” I replied, grinning at my friends and putting two fingers on each of my temples. “Hold on. Just let me access my quantum warp drive to speed things up.”

With perfect comedic timing, Bill turned toward his wife and said, “See what I’ve been putting up with all week?”

Qubits

When Bill went to retrieve two more beers from kitchen number two, the silence between Ines and me didn’t feel awkward. I think we were both enjoying a welcome respite from the sound of my voice. It was either that or the complete absence of any sound whatsoever. The breeze, which had been omnipresent since my arrival, had vanished, leaving the once-swaying trees and bushes looking as stiff as disco dancers after the music suddenly cuts off. Even the nervous chatter of the ducks had subsided, too.

“Here you go,” said Bill, handing me another ice-cold PBR. But this time, it was tucked inside a dark green beer koozie with white lettering.

“Thanks,” I replied, taking note of the cursive print. “Prestonwood . . . Is it me, or does the name sound made up? If the town of Stepford had a swanky golf course, I could see it being called Prestonwood.”

Bill, while looking at his phone, exclaimed, “Let’s see . . . The Stepford Wives movie came out in . . . wait for it . . . 1975! Another reference from the 1970s! At least you’re consistent, dude.”

“Yeah, but my stand-up routine kills at all the senior centers and nursing homes,” I added in mock defensiveness. “It seems like there’s never enough room for every wheelchair or gurney.”

“Ha-ha . . . You’re down to eight minutes,” reminded Bill.

“Okay, okay, I’m on it,” I pleaded. “It was Richard Feynman who famously said that if we want to simulate nature, then we

have to build a quantum computer. Classical computers just aren't capable of solving highly complex mathematical problems known as combinatorics."

"Combin-a-what?" asked Ines, who was sitting beside her husband with her arm resting on his shoulder.

"Combinatorics is what nature accomplishes while yawning. For the most part, they're problems associated with optimizing an arrangement of various entities toward a particular goal. As the number of entities grows, the possible arrangements grow exponentially, resulting in trial-and-error calculations that would take classical computers thousands, millions, or billions of years to work through. Remember, nature does this in an instant while yawning!"

"I'm yawning just saying combinatorics," joked Bill.

"Ha-ha . . . Yeah, but think how cool you'll sound dropping that word on the other executive board members," I said. "But first, you'll need to know about qubits. Oh, wait. You already know about them."

“No, I don’t.”

“What are Qberts?” chimed Ines.

“Ha-ha . . . qubits,” I clarified. “But I appreciate the shout-out to an old-school video arcade game. Whereas the smallest unit of data inside a classical computer is a bit in the form of a tiny transistor, a qubit is its equivalent inside a quantum computer and is in the form of a tiny quantum particle such as an electron. But instead of being either a one or a zero, it can be both at the same time. This exactly mimics the wave-particle duality we observed in the double slit experiment. It’s this duality of the qubits that allows a quantum computer to exponentially surpass the computing power of a classical computer.”

“Cool!” said Bill and Ines at the exact same time, making them both laugh at each other.

“A simple example to demonstrate the difference in the computational strength between classical and quantum computers is the ‘four-bit password test.’ Since each bit could either be a one or a zero, there would be 16 possible password

combinations using the four bits. And if only one of the combinations were correct, the classical computer would have to try each combination one by one until it found the right one. Now imagine the same test using qubits instead of bits. When the four qubits are queried for the correct password, the quantum computer, with the help of a quantum algorithm called a Grover operator, will produce the winning combination on its first try."

"Did you say 'Grover?'" asked Bill.

"Although it would've been pretty groovy if a 1970s Muppet invented the algorithm, that distinction goes to computer scientist Lov Grover, who made the monumental contribution in 1996. So, let's quickly talk about today's strong passwords, which are typically 11 characters long in a random combination of numbers, upper- and lower-case letters, and symbols. It would take over 40 years for a hacker using a fire-breathing classical computer to crack your Netflix account, and over 30,000 years if your password has 12 characters."

Ines stood up, walked around to the other side of the bar, and then disappeared. When she reemerged, she was holding a

bottle of white wine. “So, if a quantum computer can crack those strong passwords in seconds, then I’ll need to lengthen all my passwords.”

“I wouldn’t do that,” I cautioned. “Quantum computers could do it in seconds, but those machines are still eight to 10 years away. However, the ones IBM and Google are tinkering with right now could crack those 11- and 12-character passwords in a month to a year. Still, that’s a fraction of the time it would take a classical computer.”

Retaking her seat next to Bill, Ines said, “That is so cool, Chuck. So, what does a quantum computer look like? Would it fit on my desk?”

“First of all, it’s about the size of your water heater and looks like a miniature alien spaceship—if the spaceship was the offspring between a chandelier and a jellyfish. I know that sounds crazy, but if you look online, you’ll totally agree with that insane description. And since the qubits need to be informationally isolated from the effects of vibration, gravity, light, and heat, the entire quantum computer has to be in a vacuum, in total darkness, and cooled to absolute zero, which

is colder than space. So, you can count on accessing a quantum computer from the cloud."

"Oh my God! This gets more and more interesting. Why do the qubits need to be informationally isolated?"

"You can ask your husband about that, and he'll tell you about de Broglie's matter waves and tennis balls."

"You can?" replied Ines, looking at Bill and waiting for him to tell her I was joking.

Standing up from his bar stool with feigned superiority, Bill responded to his wife, "It's all part of the wave-particle duality principle of quantum mechanics, dear. Don't worry, I've got you covered."

"My husband . . . some hotshot!" quipped Ines.

"Ha-ha! I totally get that reference. It's from that old Calgon laundry detergent commercial from the 1970s. Nice one, Ines!"

“Whatever,” sighed Bill. “Let’s eat.”

Quantum Biology

Normally, I’d make a fuss if asked to sit outside to eat a meal. From experience, I already knew that separated me from the more popular nature-loving majority. But since most of my preferences, tendencies, and interests typically kept me in the minority, I was accustomed to living as one of the errant data points on a scatter plot diagram. A quick survey of the situation reminded me that I was a guest; the sun was beginning to dip behind the taller trees; there was virtually no wind to speak of; and the usual cacophony of machine noise was blissfully absent. And it was still too early in the year for mosquitoes to make everyone claw at the air like raving lunatics in between bites.

“Sure. Having dinner on the terrace sounds awesome,” I replied without a shred of protest.

I watched Ines set the table. No movement was wasted as she created an elegant setting faster than a sorceress with a magic wand. On the other hand, her husband was having a much

different experience on the other side of the terrace. From where I was standing, it looked like Bill and the grill were in some sort of wrestling match. Even from a distance, I could hear a few sordid words coming from my friend, whose idea of cursing was using words like "Dagnabbit!" and "Cheese and Crackers!" By the time he brought the barbecued chicken to the table, Ines had already put out a southern orzo salad, a broccoli cheese casserole, and a bottle of Pinot Noir—and she still had enough time to light a candle in the middle of the table.

"Gimme a second!" I blurted. "I'll be right back."

Bill was in the process of taking a seat next to his wife when he shouted, "What are you doing? We're about to eat!"

I could hear Ines tell Bill to relax as I jogged toward one of the blossoming crepe myrtle trees to pluck a waxy green leaf from behind one of its many purple blooms. When I returned to the table, I put the pilfered leaf in front of my plate and sat down across from my friends.

"And . . . what's that for?" asked Bill with a hint of annoyance.

“I’m going to make a point with it while we eat,” I replied.

Ines pushed the salad toward me and asked sarcastically, “Does it have something to do with physics?”

“How did you know?” I answered, matching her playful sarcasm.

“Well, if you don’t mind, I’m going to start eating,” interrupted Bill. “I don’t mean to be rude, but I haven’t eaten much today.”

“No worries. Please . . . go for it,” I assured my cranky and famished friend. “Ines, would it be okay with you if I talked about this seemingly unremarkable leaf for a few minutes while we ate?”

“Why are you even asking me that? You are the dinner entertainment this evening!”

“Ha-ha . . . You’re the best, Ines,” I laughed while picking up the silky leaf and holding it over my plate. “Actually, this leaf is more than just remarkable—it’s an engineering feat that

human beings haven't come close to matching. Inside this leaf are tens of thousands of tiny biological machines that turn sunlight, water, and carbon dioxide into glucose, oxygen, and usable energy for the plant to grow. More commonly known as photosynthesis, this process is nearly 100% efficient, making the most sophisticated processes mankind has ever engineered appear rudimentary and woefully inefficient in comparison."

"So physics plays a part in photosynthesis?" asked Ines.

"It not only plays a part—it plays an essential part. The process of photosynthesis begins 93 million miles away, on the surface of the sun. After an eight-minute journey to earth, thousands of trillions of red and blue light photons are absorbed by plant cells each second. The photons then make their way to organelles inside the plant cells called chloroplasts. After penetrating the chloroplasts, the photons continue into the thylakoid membranes, which are comprised of stacks and stacks of discs containing light-capturing molecules called chlorophyll. Once inside the chlorophyll, the photon interacts with a magnesium atom, creating an organic battery called an exciton. The exciton has one millionth of a

microsecond to travel to the reaction center enzyme to kick-start the actual process of photosynthesis before the battery loses its charge. Are you with me so far?"

"Definitely," replied Ines, who gave up trying to eat her chicken with utensils.

Bill looked to be regaining color in his face after getting some much-needed nourishment. "I'm with you. Keep going," he said, spooning another helping of the casserole onto his plate.

"This is where it gets really interesting," I said, sitting up more squarely in my chair to deliver the grand finale. "For such an effective and efficient process, nature really made it hard for the exciton. First of all, it can't see. Secondly, the reaction center is located far away within the thylakoid membrane. And finally, it has to get there in an instant. That would be like trying to throw the runner out at first base without knowing where first base is located. Incredibly, the exciton somehow makes it to the reaction center every single time—without losing its necessary battery charge. So, if photosynthesis were a baseball game, it would be pretty dull since nobody would ever get on base!"

“Oh my God. I think I finally understand how photosynthesis works now!” exclaimed Ines.

“Wait. It gets better,” I said, still holding the leaf over my untouched plate of food. “Quantum biologists have theorized that the exciton is able to do this because it can exist in a quantum state or have superposition, which means it possesses wave-particle duality and can be everywhere inside the chloroplast at the exact same time. While this explains how the exciton is able to locate the reaction center immediately, it opens the door to an even more fascinating question: how can the exciton exhibit this phenomenon of quantum mechanics without being informationally isolated like the qubits inside a quantum computer? Plants can’t exist in total darkness, in a vacuum, or at minus 460 degrees Fahrenheit! Pretty wild, huh?”

“That really is amazing, Chuck,” replied Bill, pushing his plate forward and reaching for the bottle of wine. “I think your passion for quantum mechanics is as interesting as wave-particle duality. I don’t think I’ve ever been as excited about anything as you are about this stuff.”

I appreciated what Bill had said but chose to let his admission hang in the air, thinking his wife would have something to say about it. Instead, she just looked at him with an expression that said, “Seriously?” making us all laugh at the same time. Taking the moment of levity as my cue to start eating, I dropped the leaf with the same flare as someone who drops the microphone.

Chapter 8: Consciousness

Who Is This Guy?

“How did I not see that before?” I whispered to myself as Bill produced a picture-perfect fire with the flip of a switch. What looked like a free-standing decorative pillar with a glass bottom was actually a gas fireplace cleverly disguised to blend into the surrounding architecture of the expansive terrace. Earlier in the evening, Bill and I had sat next to it, talking about toasters.

“I don’t know about you guys, but I’m getting pretty cold,” said Bill, urging Ines and me to join him.

There wasn’t a hint of hesitation on either of our parts, indicating that I wasn’t the only one failing to stay warm in the chilly night air. When we were all settled, I noticed that Bill and I were in the same seats as before, except his wife was sitting beside him with her legs tucked underneath her.

“Chuck, remind me of how you and Bill met all those years ago. It was during your freshman year, right?” asked Ines.

“Actually, it was before our freshman year even started,” I replied, still holding the same glass of Pinot Noir I had been nursing since dinner. “Bill and I were standing in line, waiting to get our dorm room assignments for freshman orientation. When the lady behind the counter asked Bill who he was rooming with for the weekend, he spun around and asked me, ‘You want to room together?’”

“Gees, guys are so easy like that,” blurted Ines.

“Wait. It gets better,” I added. “We ended up going to bed pretty late on our first night. It was hard to turn the engines off after such an anxious and action-packed day, knowing our every decision would end up affecting the rest of our lives. When the lights finally went out, we kept on talking for a little while longer, sharing our hopes and dreams in the forgiving anonymity of the darkness. Suddenly, out of nowhere, we heard loud voices coming from the other side of the open window. When the voices didn’t move on or get quieter, I got out of bed and peeked between the metal slats of the closed blind to see what all the ruckus was about. Strangely, I remember thinking about Mrs. Kravitz from the TV show Bewitched. ‘There are three of them out on the breezeway,’ I

reported. ‘And they’re pretty drunk.’ Bill jumped out of bed, pulled the blinds apart in one swift movement, and said through the window, ‘Take the party somewhere else. We’re trying to sleep.’”

“Oh my God! Your memory is awesome!” chimed Bill, as if he were hearing the story for the first time.

“So then one of the inebriated rednecks says, ‘Why don’t you come out here and make me?’ Before my brain could even register the sickening question as an act of full-on war, my new roommate was already getting dressed. ‘What are you doing?’ I asked. ‘I’m going to make him,’ answered Bill. ‘Jesus!’ I mumbled to myself as I began to get dressed out of sheer obligation to rule number one of Guy Code: have your friend’s back in a fight. I knew this was going to end badly—especially for me since I was clearly more of a lover than a fighter.”

“You never told me any of this!” exclaimed Ines to her husband. “Keep going, Chuck. Then what happened?”

“I followed Bill out to the breezeway, secretly wishing we were still talking about getting our share of the American Dream instead of pretending we were going to teach liquored-up Neanderthals how to be considerate of others. I watched my friend of just over twelve hours throw two punches, leaving two troglodytes meeting pavement and a third suddenly realizing it was way past his bedtime. And he wasn’t the only one who was seeing the world in a sobering new light. I wasn’t rooming with Bill from Apex. No. I was rooming with Chuck freaking Norris!”

“How in the world am I just hearing about this now?” asked Ines, looking at her husband as if he had more secrets to share.

Bill took his wife’s gushing in stride and said, “I don’t think it happened exactly like that.”

“Not only did it happen like that, I instantly became the president of your fan club and wouldn’t shut up about it for the rest of the weekend,” I added. “By the time everyone went home after orientation, the legend of Bill had morphed into Biblical proportions. At one point, I recall overhearing

someone say, ‘He took on a whole biker gang in front of the Blimpie sandwich shop on Hillsborough Street.’”

“Ha-ha . . . Oh my God! That’s awesome!” laughed Ines. “My husband: He really is a hotshot!”

Classical or Quantum?

“You’re not going to punch me in the face if I start talking about quantum physics again, are you?” I joked, looking at Bill with pseudo-trepidation.

“Ha-ha . . . No, but don’t keep me up past my bedtime. After that, you’re on your own.”

“You got it, Cinderella,” I teased. “So, the question remains: Do you think the human brain is more like a classical digital computer? Or more like a quantum computer?”

“Quantum computer!” blurted Bill and Ines at the exact same time, again making them laugh at themselves for sharing the same brain.

“Then you’d be in good company because British mathematician and Nobel Laureate Roger Penrose just so happens to think the same thing. Unfortunately, his theories aren’t widely accepted by the scientific community. Leading the opposition is Max Tegmark, a Swedish-American cosmologist and physics professor at MIT. He believes the human brain is more like a classical computer because it’s too warm, too wet, and too messy of an environment to support quantum superposition. Plus, even if wave-particle duality could exist in the brain, it would collapse way before neuronal activity could take place.”

“What do you think, Chuck?” pried Ines.

I noticed the firelight dancing across both their faces, making their eyes shine like primal beings sizing me up from the safety of distant shadows. “I tend to agree with Max because he also said that his opinion could change (though he’s not betting on it) once quantum computers become more stable in the future. Historically, the human brain has always been a conundrum for scientists. They can show you a map of the universe and point out where Earth is located, but these same brilliant minds can’t tell you what their fellow scientists are

thinking. When crop irrigation began around 6000 B.C., theorists at the time believed that the brain functioned in the same way—delivering life energy to different parts of the brain via defined channels. And when the Industrial Revolution was in full swing in the late 1700s, scientists likened the brain to a system of biological levers, pulleys, and gears. And now that we live in the digital computer age, it's only natural to compare our brains to an Intel microchip. But to be honest with you, I don't find this very interesting. For me, the real fascination centers around whether or not quantum mechanics underpins human consciousness."

It was then that I wished the three of us were sitting around a real campfire. What better backdrop could there be while contemplating one's own existence? Yet the current setting was still better than expected. Despite a hissing sound accompanying the gas flames (rather than random pops and crackles from a real fire), they still made the shadows wiggle as if only they could hear the music of the night.

"Don't worry," I continued. "I'm not getting ready to launch into a sales pitch about the benefits of vibrational resonance therapy using crystals or anything."

“Dang it! I was hoping Ines and I could finally break out our Tibetan singing bowls. Could we at least light some incense?”

“Ignore him, Chuck. I like where you’re going with this. Are you saying that quantum mechanics can explain consciousness?”

“It’s a possibility. But first, we have to start with Mendeleev’s periodic table.”

An Elementary Explanation

When Bill went into the house to use the bathroom, another moment of silence descended upon Ines and me. But this time, the sound of the swaying trees and fluttering leaves made the ducks feel safe enough to reveal their presence once again, filling the quiet void until Bill returned.

“I bet if you closed your eyes, you could still see the oversized periodic table that hung on the wall in one of your high school science classes,” I said, inching a little closer to the fire since the wind had picked back up.

“I can,” answered Bill.

“Me, too,” added Ines.

“What’s so cool is that the 118 elements organized on it make up everything in the known universe. What’s even cooler is that 22 of them can be found in your own body. As we sit here, all three of us are about 65% oxygen, 18% carbon, 10% hydrogen, and 3% nitrogen. The remaining 4% is made up of the other 18 elements, all of which were created long before the earth was even formed. I think it’s pretty mind-blowing to know that all the elements inside me were cooked within stars before they exploded as supernovae. Even crazier sounding is that the hydrogen inside me came from the Big Bang 13.7 billion years ago!”

“So, then, you’re saying we’re nothing more than nuclear waste?” quipped Bill.

“I don’t like that,” said Ines.

“Technically, you’re absolutely right, Bill. But I prefer to think of us as stardust rather than nuclear waste.”

“Oh, I like the sound of that much better,” blurted Ines, before jumping up and excusing herself for a bathroom break.

In her absence, Bill took the opportunity to tell me that Ines was loving the conversation.

“How do you know?” I asked.

“Because she was planning to go back to work upstairs after we ate. You know, the whole FDA thing she mentioned earlier. She gets bored easily if she’s presented with a perspective she’s heard before. So, congratulations! You’re not boring my wife!”

“What are you guys laughing about?” pried Ines before reclaiming her seat next to Bill.

“Nice sweatshirt,” I replied, changing the subject to the oversized hooded sweatshirt she had slipped on before coming back outside. “You’re such a homer.”

“Why? What’s wrong with it?” she asked, pulling the bottom hem down to better display the word ‘WOLFPACK’ against a perfect shade of NC State red.

“Nothing. Now I’m feeling bad for not owning a single thing that says ‘NC State’ on it. May I continue steering the conversation toward the abstraction of consciousness? Or should we address my lack of school spirit?”

“Ha-ha . . . Please continue, Chuck. Remember, I have an early flight tomorrow,” added Bill, making me think he was half serious.

“Okay, okay, I’m on it. So, I mentioned that out of the 118 elements on the periodic table, 22 can be found in the human body. I think that’s mildly interesting. What’s more interesting is that the human body has more atoms inside it than there are stars in the universe. And just so you know, there are more stars in the universe than grains of sand on every beach on earth! Right now, as you’re listening to me, there is nothing about your physical presence that isn’t comprised of those 22 elementary atomic particles. But the truly amazing thing is that atoms essentially live forever. So, when we pass away, our

biological processes will cease to function, but the seven octillion atoms inside us (that's a seven with 27 zeros after it) will continue on. Back in the mid-1990s, I attended a lecture by prominent alternative medicine advocate Deepak Chopra in Thousand Oaks, California. In it, I remember him saying that it was entirely possible for some audience members to possess recycled atoms from Ramesses II, Aristotle, and Julius Caesar—even from a palm frond carried by Cleopatra, symbolizing eternal life. Okay, I added that last part about Cleopatra."

"Ha-ha . . . Nice touch, Chuck," joked Ines, scrunching up against Bill in an attempt to get closer to the fire.

"That is interesting," said Bill. "I never thought about life and death in those terms."

"So, then, the million-dollar question is that if our bodies and brains are nothing more than an atomic construct of stardust, then what can account for our emotions like love, passion, and curiosity? What can explain the soul, the spirit, or the voice deep within us? Where does the notion of right and wrong come from? To me, our inner selves, thoughts, feelings, and

emotions are simply manifestations of consciousness. Think about it. We're made up of atoms that are billions of years old, yet we can contemplate our own existence. C'est fou!"

"Say what?" asked Bill.

"It means 'that's crazy' in French," I explained. "Sorry, I was looking for a clever way to segue into talking about a French mathematician and philosopher who famously said (in Latin), 'Cogito, ergo sum.' I think, therefore I am."

"Well, I think you should write a book about this stuff, Chuck," offered Ines.

"You know . . . I just might do that."

Schools of Consciousness

When Bill and Ines noticed that I was staring up into the night sky, I was tempted to tell them what I was really thinking. Instead, I said what was expected: "Wow! There sure are a lot of stars out tonight." Then I listened to them tell me how their location in the middle of a utopian golf resort made it the

perfect place to have a telescope—and that spring was the best season for stargazing. What I didn't say was how the departing twilight reminded me of the ocean. Like a retreating tide leaving behind an array of colorful pebbles and delicate shells, the fading sun left behind an abundance of nighttime jewels laid out against a sky of black velvet.

"Descartes, right?" pried Bill, stretching his legs across the glass-topped coffee table between us, indicating that his bedtime ritual was soon to commence. "I didn't know he was the one who said that famous quote, but I do know that he bridged the gap between algebra and geometry, setting Newton on course to invent calculus."

"Ding, ding, ding! We have a winner! Pick any prize from the bottom shelf, sir!" I replied in my most annoying carnival barker voice. "Nice one, Bill. But René Descartes is also credited with introducing mind-body dualism, a nearly 400-year-old philosophical theory that distinguishes the mind and body as two different forms of matter. His way of thinking, which encompasses things like metaphysics and spirituality, is one of three popular schools of thought centered around the mysteries of consciousness."

Bill removed his feet from the table and leaned forward with his elbows on his knees. “First of all, my prize is my wife, and I picked her off of the top shelf. Thank you very much.”

“Ha-ha . . . I stand corrected.”

Cradling Bill’s arm in her lap, Ines asked, “Chuck, what’s the difference between metaphysics and spirituality?”

“Great question, Ines. Metaphysics is a philosophical discussion seeking to explain the world we live in and our place in it. Spirituality, on the other hand, is more experiential and focuses on practices leading toward personal development and self-discovery. In my opinion, a person can still be considered spiritual even if they’re not affiliated with a particular religion. I see religious organizations in the same way I see footwear in a sporting goods store—Adidas is good for runners with a high arch, Nike accommodates moderate arches, and New Balance caters to the more flat-footed joggers—all of them having the same goal in mind.”

“I’m pretty sure Bill and I are wearing Nikes,” quipped Ines. “How about you, Chuck? What are you wearing?”

“I’m not wearing anything since I run on the grass,” I replied, smiling at my friends and looking to see if they were catching my drift.

Sensing that Bill and Ines weren’t looking to go down a rabbit hole debating the differences between religion and spirituality, I changed the subject by asking them if they wanted to know what the other schools of thought had to say about consciousness.

“Go for it,” urged Bill.

“So, imagine if someone were dying from terminal cancer yet suddenly began to show signs of remarkable improvement. After several years of continuous remission, baffled doctors would scratch their heads while deeming the patient cured from what surely should’ve killed them. As a believer in Descartes’ mind-body dualism, you might credit prayer, meditation, or divine intervention for such a miraculous turnaround. If you lean more toward reductive materialism, you may chalk it up as a lucky outcome of random biological processes within the patient’s body. Reductive materialists believe that only the material world is real—that everything in

the universe (including consciousness) can be explained by the interaction of the most elementary units of matter like subatomic particles, atoms, and molecules."

"Very interesting," said Ines, looking as if she was only gaining steam as the evening progressed. "Didn't you say there were three schools of thought?"

"I said there were three popular schools of thought."

Bill stretched both arms over his head, giving me the universal signal that it was getting close to calling it a night. "So, what's the third?" he asked.

"It's simply the belief that human consciousness is so unique and so perplexing that we've yet to figure it out. But many scientists and physicists (like Roger Penrose) adamantly believe that the answer lies within the principles of quantum mechanics, such as wave-particle duality, quantum tunneling, and quantum entanglement. Personally, I'm in agreement with this school of thought, but I also resonate with a quote from Albert Einstein, who famously said, 'All religions, arts, and sciences are branches of the same tree.'"

“I like that, Chuck,” sighed Ines, tilting her head back to look amongst the stars as if the secret to life’s greatest enigma would suddenly come to her like the answer to an impossibly difficult crossword clue.

“See something you like up there?” I asked, standing up to say goodnight and prove that I wasn’t overstaying my welcome.

“You’ve given me a lot to think about,” replied Ines, rising to her feet a moment before Bill followed her lead.

“I guess this is goodnight,” I said.

Bill put his arm around his wife’s shoulders and said, “We’ll walk you out, Chuck.”

The three of us walked in silence across the terrace toward the house. They followed me as I retraced the same path Bill and I took hours earlier. Sometimes those walks to the door after an evening with friends can be a bit awkward—especially if there’s a prolonged silence. But this wasn’t the case. The silence was comfortable and validating, as if there needed to be an acknowledged gestation period for what had just been

consumed both intellectually and spiritually. For a minute, nothing could be heard—not even the ducks.

Chapter 9: Conclusion

The Promise

Hugs started out as handshakes, followed by heartfelt goodbyes and sincere promises to do this again real soon. I reluctantly turned away from my friends, asking myself, "How could more than 40 years have passed so quickly?" Recalling the hopes and dreams Bill had shared with me while we lugged textbook-laden backpacks to and from the campus library, I could see that my friend had achieved most, if not all, of what he was aiming for. Back then, our goals weren't dissimilar—two ambitious young men who could apply themselves and avoid the obvious pitfalls that swallowed most of the boys. If you were the betting kind, you wouldn't know who to put your money on. Had you asked me as an 18-year-old, I would've told you that the safer bet was with Bill. On the surface, my future looked as bright as his, but deep down, I was already beginning to dig my heels in at the thought of trading freedom and flexibility for fame and fortune. In the end, we both won. Still, I couldn't help but think we were saying our farewells from two very different mountaintops.

“Chuck, aren’t you forgetting something?” asked Bill, making me spin around while feeling the outside of my pockets for shapes matching a phone and a set of keys.

“No, I don’t think so . . . Oh, wait! Now I remember! How could I forget?” I replied, taking a couple of steps toward the illuminated doorway to deliver on a promise reminiscent of Babe Ruth pointing his bat at the centerfield seats before stepping into the batter’s box. “So, is it true?”

“Without a doubt, Chuck.”

“What are you guys talking about?” Interjected Ines.

“You want to do the honors?” I asked, hoping Bill would phrase it the same way I did when I invited him to meet me at Tom’s place a week earlier.

“Sure, but then I want you to tell me why it’s true.”

“Of course. It’s a pretty straightforward theory that you won’t find anywhere else. It came to me while sitting at a traffic light about five years ago.”

Like an anxious drama teacher watching their student perform in their first theatrical production, I caught myself nodding and mouthing some of the words as Bill explained to his wife what I had promised him over the phone. When he was finished, Ines turned and looked at me with an expression that told me she hadn't lost her youthful curiosity.

"So, you told my husband that after demonstrating and explaining everything about the double-slit experiment, he would feel happier?"

"Basically, yes. That includes everything we did at my friend's house and at his lab, what we talked about during our hike yesterday, and this evening."

Ines smiled and said, "Well, I only got to listen to the last part of the lecture series, and I'm feeling happier, too."

"So, why is that?" asked Bill and Ines at the exact same time again, prompting me to laugh with them.

"Maybe you should come back inside," suggested Bill. "It's pretty chilly."

Shocked that my friend was no longer exhibiting signs of tiredness, I declined and said, “I’ll just tell you right here. It won’t take but a minute, okay?”

“Let’s hear it, Chuck,” replied Bill, pulling Ines closer as if he were steadying himself for a long-winded dissertation.

“Don’t worry,” I assured the audience of two. “It’s really quite simple.”

The Gift

“So, you were sitting at a traffic light and . . . what came to you?” pressed Bill.

“After sitting through a third red light at the same intersection, I remember something profound, even cathartic, flooding my mind and putting the brakes on an in-process meltdown that was well on its way to cracking the top ten tirades in my personal hall of shame. Suddenly, I understood there was a way to rise above the soul-crushing frustration of everyday life in America. However, that way would have to run through a

part of me that was woefully neglected. It would require the being inside me."

Ines reached across her body to hug Bill. Now both her arms were around him while they stood looking at me. If I had to guess, her sudden appreciation for the moment seemed to be out of sheer enjoyment of this new revelation rather than the quickest way to combat the gathering cold.

"What do you mean by the being inside you?" asked Bill from the jaws of a big red sweatshirt.

"Okay, let me explain it to you in terms of the roles you have in your life. Based on what I know about you, you're a son, brother, father, husband, uncle, ice hockey coach, and the president of your company, right?"

"You got it," answered Bill. "But I also teach a weekly CCD class. It's for the kids whose families belong to our church but attend public schools. Would that be another role of mine?"

"Absolutely, but I'd label that role as being a member of the Catholic church since you most likely have other duties and

responsibilities as an active parishioner. Oh, and the answer is no if you think playing disc golf is another role. Sorry, but that's an obsession, chief."

"Not even if I won the last two tournaments I entered?"

"Ha-ha . . . What's funnier (if you could call it that) is that a lot of people aren't even aware of the three additional roles that were assigned to them at birth. In fact, when pressed, most aren't able to name them. In your case, Bill, and in no particular order, they would be man, human being, and being. From my observations, most people spend their time vacillating between all their roles except the three I just mentioned. But in their defense, I don't think society provides enough awareness and education around these three critically important roles. Instead, people are busy being mothers, truck drivers, social media influencers, grandfathers, and project managers—all of them understanding that the amount of tangible and intangible rewards depends on their level of commitment and personal investment. For example, a hands-on dad might reap the benefits of having a loving relationship with his children throughout his life. Or an energy sales rep might become a regional vice president after successful stints

in Saudi Arabia and Yemen. So, what do you think the costs are for ignoring your role as a being?"

"You're asking me? Umm . . . I guess that would mean . . ."

"Let me explain it another way," I interrupted. "You'd probably agree with me that a person's overall health is as strong as its weakest component, right? And if you believe overall health is based on a combination of physical fitness, mental health, social connectivity, and spiritual enlightenment, then you'd agree that neglect of one or more of these components would have a negative impact on someone's overall health status, right? Would you consider a person healthy if they were spiritually bankrupt? What if they were physically fit but despised the opposite sex after a particularly nasty divorce? True wellness comes from investing in all aspects of health, not just one or two. So, with that being said, it's the same for the roles you have in your life."

"How so?" asked Ines.

“Your overall happiness is as strong as your weakest effort in your most neglected role. And from my observations, the roles of gender, human being, and being are the most commonly neglected. Topping the list, in my opinion, is the being inside us. But in our defense, if we haven’t been taught how to be men, women, or human beings, how on earth are we supposed to know how to be a being? Yet, here we are—all of us holding undeniable membership cards to the very universe that made us—without having the first clue on how to acknowledge and nurture such an essential part of us.”

“Really? All of that came to you at a traffic light five years ago? And you’re just now letting us know about it?” asked Bill, paying no mind to the fact that I had already exceeded my one-minute explanation goal.

“It’s true,” I admitted, suddenly realizing I was rocking back and forth on both feet and using my hands a lot—telltale signs I was in the zone. “But recognizing the being within me wasn’t enough. I had to figure out how to feed it. As it turns out, the being needs to learn everything it can about the universe we live in. And when it does, it . . .”

“It doesn’t feel as neglected, and your overall happiness improves as a result, right?” interrupted Bill.

“Yes, that’s right,” I assured. “But I was going to say that it gives you a tremendous gift. Just like being a compassionate and patient husband can reward you with an ever-loving and appreciative wife, an investment in the being within you can result in a transcendental practice that you’ll cherish for the rest of your life.”

“Chuck, I love knowing this,” beamed Ines.

“Now that you’ve been reminded of the being inside you and what it needs in order to grow and flourish, you can take full advantage of what the being brings to your life. So, the next time you’re feeling anxious, overwhelmed, frustrated, or heartbroken, just remember that the being is unaffected by such earthbound and manmade problems. Traffic congestion, unfair business practices, inconsiderate neighbors, and surly coworkers are of no consequence to the being inside you. Not even a lack of love, family, or friends can disrupt the being’s sentient connection with the exquisiteness of the universe. The being’s home is calm, simple, and purposeful. It lives in a

place that's accessible because that place is inside you. And that's why I wanted to tell you about the phenomenon of wave-particle duality through the famous double-slit experiment. The being inside you exists, and it needs to be acknowledged and fed. And when that happens, you can't help but feel happier."

My final thoughts hung in the air like a sky-high Hail Mary pass. I imagined the game clock's double zeros reflecting off of every riveted eyeball in attendance. I could see the crowd—fans, vendors, coaches, players, even the television audience—all watching and waiting for the gorgeous arc to find purchase in an improbable ending that would send everyone home feeling as light as clouds.

"That's beautiful, Chuck," said Ines.

"I agree. Great message, buddy," added Bill.

After a second round of goodbyes, I turned away from my friends to begin walking toward my truck. I knew they were still watching me since the light spilling from the open front door didn't dim against the shrubbery in front of me. When

the door did close, something in the night sky caught my eye. I wasn't sure if it was a shooting star or not. But when I hopped into the cab of the truck, I suddenly felt more calm, simple, and purposeful, leaving me without a doubt that it was a shooting star. The being inside me must've seen it.

The End

About the Author

Chuck Trunks is a writer and artist who grew up in suburban Philadelphia. After earning a Bachelor of Science degree in Biology from North Carolina State University, Chuck had a successful 19-year career in positions ranging from genetic engineer to software developer to business analyst at Amgen, Inc. in Thousand Oaks, California. During his tenure in the biotech industry, he traveled extensively throughout the United States, Europe, and the Caribbean. For inspiration, he bicycles, runs, and reads whatever he can get his hands on.

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Additional Books by Chuck Trunks

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Being Happy: The Pursuit of You

It's Not Your Fault: But it Could Be

Physics from the Heart: A Quantum Story

Be Still My Heart: A Code for Love

Silver Linings: In a Mad World

Spot Me: A Gym Memoir

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