

Quantum Enigma
Physics Encounters
Consciousness

Second Edition

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1

Einstein Called It “Spooky” And I Wish I Had Known

I have thought a hundred times as much about the quantum problem as I have about general relativity theory.

—Albert Einstein

I cannot seriously believe in [quantum theory] because

. . . physics should represent a reality in time and space, free from spooky action at a distance.

—Albert Einstein

I was visiting friends in Princeton one Saturday in the 1950s when our host asked his son-in-law, Bill Bennett, and me (Bruce) if we'd like to spend the evening with his friend, Albert Einstein. Two awed physics graduate students soon waited in Einstein's living room as he came downstairs in slippers and sweatshirt. I remember tea and cookies but not how the conversation started.

Einstein soon asked about our quantum mechanics course. He approved of our professor's choice of David Bohm's book as the text, and he asked how we liked Bohm's treatment of the strangeness quantum theory implied. We couldn't answer. We'd been told to skip that part of the book and concentrate on the section titled “The Mathematical Formulation of the Theory.” Einstein persisted in exploring our thoughts about what the theory really meant. But the issues that concerned him were unfamiliar to us. Our quantum physics courses focused on the *use* of the theory,

not its meaning. Our response to his probing disappointed Einstein, and that part of our conversation ended.

It would be many years before I understood Einstein's concern with the mysterious implications of quantum theory. I did not know that back in 1935 he had startled the developers of quantum theory by pointing out that the theory required an observation at one place to *instantaneously* influence what happened far away *without involving any physical force*. He derided this as "spooky action" that could not actually exist.

Einstein was also bothered by the theory's claim that if you observed a small object, an atom, say, to be someplace, it was your *looking* that caused it to be there. Does that apply to big things? In principle, yes. Ridiculing quantum theory, Einstein once asked a fellow physicist, only *half-jokingly*, if he believed the moon was there only when he looked at it. According to Einstein, if you took quantum theory seriously, you denied the existence of a physically real world independent of its observation. This is a serious charge. Quantum theory is not just one of many theories in physics. It is the framework upon which *all* of physics is ultimately based.

Our book focuses on the mysterious implications of quantum theory that bothered Einstein, from his initial proposal of the quantum in 1905 to his death a half-century later. But for many years after that evening with Einstein, I hardly thought about the quantum weirdness, which physicists call "the measurement problem." As a graduate student, I puzzled about the related "wave-particle duality." It's the paradox that, looking one way, you could demonstrate an atom to be a compact object concentrated in one place. However, looking differently, you could demonstrate exactly the *opposite*. You could show that the atom was *not* a compact object, that it was a wave spread out over a wide region. That contradiction puzzled me, but I assumed that if I spent some hours thinking it through, I'd see it all clearly—the way my professors seemed to. As a graduate student, I had more pressing things to do. My Ph.D. thesis involved lots of quantum theory, but like most physicists, I had little concern with the theory's deeper meaning, which I then didn't realize goes well beyond mere "wave-particle duality."

After a decade in industrial physics research and research management, I joined the faculty at the University of California, Santa Cruz (UCSC). Teaching a physics course for liberal arts students, the mysteries

of quantum mechanics intrigued me. A weeklong conference in Italy on the foundations of quantum mechanics left me hooked on what I was unprepared to talk about that long-ago evening in Princeton.

When I (Fred) encountered quantum mechanics in my junior year at MIT, I wrote Schrödinger’s equation across the page of my notebook, excited to see the equation that governed everything in the universe. Later I puzzled about the quantum assertion that an atom’s north pole could point in more than one direction at the same time. I wrestled with this for a while but gave up, figuring I’d understand it after I learned more.

For my Ph.D. dissertation I did a quantum analysis of magnetic systems. I had become facile in *using* quantum theory, but I had no time to think about what it *meant*. I was too busy trying to publish papers and get my degree. After working with a couple of hi-tech companies, I joined the physics faculty at UCSC.

When the two of us started to explore the boundary where physics meets speculative philosophy, our physics colleagues were surprised. Our previous research areas were quite conventional, even practical. (There is more about our backgrounds in industrial and academic research, and contact information, on our book’s website: www.quantumenigma.com.)

The Skeleton in Physics’ Closet

Quantum theory is stunningly successful. Not a single one of the theory’s predictions has ever been shown wrong. One-third of our economy depends on products based on it. However, the worldview demanded by quantum theory is not only stranger than we might suppose, it’s stranger than we *can* suppose. Let’s see why.

Most of us share these commonsense intuitions: A single object can’t be in two far-apart places at once. And, surely, what someone decides to do here cannot instantly affect what happens someplace far away. And doesn’t it go without saying that there’s a real world “out there,” whether or not we look at it? Quantum mechanics challenges each of these intuitions. J. M. Jauch tells us: “For many thoughtful physicists, [the deeper meaning of quantum mechanics] has remained a kind of skeleton in the closet.”

We started out telling of Einstein's troubled concern with quantum theory. What is quantum theory? Quantum theory was developed early in the twentieth century to explain the *mechanics*, the mechanism, governing the behavior of atoms. Early on, it was discovered that the energy of an object could change only by a discrete quantity, a *quantum*, hence "quantum mechanics." "Quantum mechanics" includes both the experimental observations and the quantum *theory* explaining them.

Quantum theory is at the base of every natural science from chemistry to cosmology. We need quantum theory to understand why the sun shines, how TV sets produce pictures, why grass is green, and how the universe developed from the Big Bang. Modern technology is based on devices designed with quantum theory.

Prequantum physics, "*classical mechanics*," or "classical physics," also sometimes called "Newtonian physics," is usually an excellent approximation for objects much larger than molecules, and it's typically much simpler to use than quantum theory. It is, however, only an approximation. It does not work at all for the atoms that everything is made of. Nevertheless, classical physics is basic to our conventional wisdom, our Newtonian worldview. But we now know this classical worldview is fundamentally flawed.

Since ancient times, philosophers have come up with esoteric speculations on the nature of physical reality. But before quantum mechanics, one had the logical option of rejecting such theorizing and holding to a straightforward, commonsense worldview. Today, quantum experiments deny a commonsense physical reality. It is no longer a logical option.

Might a worldview suggested by quantum mechanics have relevance beyond science? Consider earlier discoveries that did have such relevance: Copernicus's realization that Earth was not the center of the cosmos, or Darwin's theory of evolution. The relevance of quantum mechanics is, in a sense, more immediate than Copernican or Darwinian ideas, which deal with the far away or long ago. Quantum theory is about the here and now. It even encounters the essence of our humanity, our consciousness.

Why, then, hasn't quantum mechanics had the intellectual and societal impact of those earlier insights? Perhaps because they are easier to comprehend. They are certainly *much* easier to believe. You can roughly summarize the implications of Copernicus or Darwin in a few sentences.

To the modern mind, at least, they seem reasonable. Try summarizing the implications of quantum theory, and what you get sounds mystical.

We risk a rough summary anyway. Quantum theory tells that the observation of an object can instantaneously influence the behavior of another greatly distant object—even if no physical force connects the two. These are the influences Einstein rejected as “spooky actions,” but they have now been demonstrated to exist. Quantum theory also tells us that an object can be in two places at the same time. Its existence at the particular place where it happens to be found becomes an actuality *only upon its observation*. Quantum theory thus denies the existence of a physically real world independent of its observation. (We’ll see “observation” to be a tricky and controversial concept.)

Strange quantum phenomena can be *directly* demonstrated only for small objects. Classical physics describes the reasonable behavior of big things to an *extremely* good approximation. But the big things are made up of the small things. As a worldview, classical physics just does not work.

Classical physics explains the world quite well; it’s just the “details” it can’t handle. Quantum physics handles the “details” perfectly; it’s just the world it can’t explain. You can see why Einstein was troubled.

Erwin Schrödinger, a founder of modern quantum theory, told his famous cat story to emphasize that quantum theory says something “absurd.” Schrödinger’s unobserved cat, according to quantum theory, was simultaneously dead *and* alive until your observation of it *causes* it to be either dead or alive. Here’s something even harder to accept: Finding the cat dead creates the history of its developing rigor mortis. Finding it alive creates the history of its developing hunger. *Backward in time*.

The enigma posed by quantum theory has challenged physicists for eight decades. Perhaps the particular expertise and talents of physicists does not *uniquely* qualify us for its comprehension. We physicists might therefore approach the problem with modesty, though we find that hard.

Remarkably, the quantum enigma can be presented essentially full-blown without involving much physics background. Might someone unencumbered by years of training in the *use* of quantum theory have a new insight? It was a child who pointed out that the emperor wore no clothes.

Controversy

Our book originated with a wide-ranging physics course for liberal arts students that in its last weeks focused on the mysteries of quantum mechanics. When I (Bruce) first proposed the course at a department meeting, that final focus prompted a faculty member to object:

Though what you are saying is correct, presenting this material to nonscientists is the intellectual equivalent of allowing children to play with loaded guns.

That objecting faculty member, a good friend, had a valid concern: Some people, seeing the solid science of physics linked with the mystery of the conscious mind, might become susceptible to all sorts of pseudo-scientific nonsense. My response was that we'd teach "gun-safety": We'd emphasize the scientific method. The course was approved. Fred now teaches it, and it's become the most popular course in our department.

Let's note straightaway that the encounter with consciousness in our title does not imply "mind control," that your thoughts alone can *directly* control the physical world. Do the undisputed results of the quantum experiments we describe imply a mysterious role for consciousness in the *physical* world? It's a hotly debated question arising at a boundary of the physics discipline.

Since our book focuses on that boundary, where the quantum enigma emerges, it is necessarily a controversial book. However, absolutely *nothing* we say about quantum mechanics itself is controversial. It is the mystery these results imply *beyond* the physics that is controversial. For many physicists, this baffling weirdness is best not talked about. Physicists (including ourselves) can be uncomfortable with their discipline encountering something as "unphysical" as consciousness. Though the quantum facts are not in dispute, the meaning *behind* those facts, what quantum mechanics tells us about our world, is hotly debated. Addressing them in a physics department, especially in a physics class or to a non-technical audience, will incur the disapproval of some faculty. (Physicists, of course, are not alone in their discomfort with the issue of consciousness arising mysteriously in the discussion of physical phenomena. It can challenge the worldview of any of us.)

An Einstein biographer tells that back in the 1950s a non-tenured faculty member in a physics department would endanger a career by showing any interest in the strange implications of quantum theory. Times are changing. Exploration of the fundamental issues in quantum mechanics, which cannot avoid encountering consciousness, increases today and extends beyond physics to psychology, philosophy, and even computer engineering.

Since quantum theory works perfectly for all *practical* purposes, some physicists deny there’s any problem. Such denial abandons to the purveyors of pseudo-science the aspects of quantum mechanics that understandably most intrigue non-physicists. The movie *What the Bleep?* is an example of the pseudo-science we deplore. (If you’re unfamiliar with *Bleep*, see our comment early in chapter 15.) The *real* quantum enigma is more bizarre and more profound than the “philosophies” such treatments espouse. Understanding the real quantum mystery requires a bit more mental effort, but it’s worth it.

At a physics conference attended by several hundred physicists (including the two of us), an argument broke out in the discussion period after a talk. (The heated across-the-auditorium debate was reported in the *New York Times* in December 2005.) One participant argued that because of its weirdness, quantum theory had a problem. Another vigorously denied there was a problem, accusing the first of having “missed the point.” A third broke in to say, “We’re just too young. We should wait until 2200 when quantum mechanics is taught in kindergarten.” A fourth summarized the argument by saying, “The world is not as real as we think.” Three of these arguers have Nobel Prizes in Physics, and the fourth is a good candidate for one.

This argument recalls an analogy that reflects our own bias. A couple is in marriage counseling. The wife says, “There’s a problem in our marriage.” Her husband disagrees, saying, “There’s *no* problem in our marriage.” The marriage counselor knows who’s right.

Interpreting Quantum Theory

In the last twenty years of his life, Einstein’s continued challenging of quantum theory was often dismissed as his being out of touch with

modern physics. He was indeed wrong in denying the reality of the “spooky action” he discovered to lurk in quantum theory. Its existence, now called “entanglement,” has been demonstrated. Nevertheless, Einstein is today recognized as the theory’s most prescient critic. His constant claim that the theory’s weirdness must not be brushed aside is borne out by today’s proliferation of wild interpretations of quantum theory.

In chapter 15 we describe several contending views, interpretations, of what quantum mechanics is telling us about the physical world—and, perhaps, about us. These are all serious proposals developed with extensive mathematical analysis. They variously suggest observation creating a physical reality, the existence of many parallel worlds with each of us in each of them, a universal connectedness, the future affecting the past, a reality beyond physical reality, and even a challenge to free will.

At the boundary where physics no longer compels consensus, the meaning of quantum theory is controversial. Most interpretations of what’s going on show how the issue of consciousness can be ignored for all *practical* purposes. However, in exploring the theory’s foundations, most contemporary experts admit a mystery, usually one encountering consciousness. Although it is our most intimate experience, consciousness is ill defined. It’s something physics can’t treat, but can’t ignore.

Physics Nobel Laureate Frank Wilczek recently commented:

The relevant literature [on the meaning of quantum theory] is famously contentious and obscure. I believe it will remain so until someone constructs, within the formalism of quantum mechanics, an “observer,” that is, a model entity whose states correspond to a recognizable caricature of conscious awareness. . . . That is a formidable project, extending well beyond what is conventionally considered physics.

As we present the undisputed facts, and emphasize the enigma they challenge us with, we propose no resolution of the enigma. We rather offer readers a basis for their own pondering. Remarkably, this controversial issue can be understood with little prior knowledge of physics.

2

The Visit to Neg Ahne Poc **A Quantum Parable**

If you're going to ham it up, go the whole hog.

—G. I. Gurdjieff

A few chapters will go by before we encounter the enigma posed by quantum mechanics. But let's start out with a look at the paradox. With today's technology we can display the quantum enigma only with tiny objects. But quantum mechanics supposedly applies to everything.

So we begin by telling a story in which a physicist visits Neg Ahne Poc, a land with a magical technology that allows displaying something *like* the quantum enigma with large objects, a man and a woman, instead of atoms. Our parable tells of something impossible in the real world, but watch for what baffles our visitor to Neg Ahne Poc. His *bafflement* is the point of our parable. In later chapters you should experience a similar bafflement.

Prologue by Our Self-Assured Visitor to Neg Ahne Poc


Let me tell you why I'm slogging up this steep trail. Since quantum mechanics can make Nature appear mystical, some people can be misled into accepting supernatural foolishness.


Last month I was with some usually sensible friends in California. People there, however, seem particularly susceptible to quantum nonsense. My friends spoke of the "Rhub" in Neg Ahne Poc, a village high in the Hima-Ural Mountains. They claimed this shaman could display quantum-like phenomena with large objects. That's ridiculous, of course!


When I explained to them that such a demonstration is impossible, they accused me of being a closed-minded scientist. I was challenged to investigate. One of them, a dot-com billionaire, who admits that selling his company only months before the bust was just dumb luck, offered to fund my trip. Colleagues in the physics department urged me not to waste my time on a wild-goose chase, that I had better do serious physics and publish if I'm going to get tenure. But I believe that a public-spirited scientist should expend some effort investigating unjustified notions to prevent their propagation. So here I am.


I'll look into this stuff with a completely open mind. I'll then debunk this nonsense when I get home. But while I'm in Neg Ahne Poc, I'll be discreet. This shaman's trickery is likely part of the local religion.


The trail becomes less steep and broadens to end suddenly in a modest plaza. Our visitor has arrived in Neg Ahne Poc. He is relieved to see that his friends' long-distance arrangements have worked. His arrival is expected. He is warmly greeted by the Rhob and a small group of villagers.

 Greetings, Curious Questioner, Careful Experimenter. You are a welcome visitor to our village.


 Thank you, thank you very much. I appreciate the warm welcome.

 We are happy to have you with us. I understand you seek a truth. Since you are an American, I am sure you want it quickly. We will try to accommodate, but please sympathize with our unhurried ways.


 Oh, I appreciate that. I hope I will not be much trouble.


 Not at all. I understand that you physicists just recently, in the past century, as a matter of fact, have learned some of the deeper truths of our universe. Your technology limits you to working with small and simple objects. Our "technology," if you wish to call it that, can provide a demonstration with the most complex entities.

 (ENTHUSIASTICALLY, BUT SUSPICIOUSLY) I'd be eager to see that.


 I have made such arrangements. You will ask an appropriate question, and the answer to your question will then be revealed to you. I believe the procedure of posing a question and having an answer

revealed is much like what you scientists call “doing an experiment.” Do you wish this experience?


 (LOOKS PUZZLED) Why, yes I do


 I will prepare a situation to allow that experiment.


The Rhob motions toward two small huts about twenty yards apart. Between the huts a young man and a young woman stand holding hands.

 Arranging our situation, “preparing the state” you would call it, must be done without observation. Please don this hood.


Our visitor places the soft black hood over his head. The Rhob soon continues.

 The state is now prepared. Please remove the hood. In one of these huts there is a couple, a man and a woman together. The other hut is empty. Your first “experiment” is to determine which hut holds the couple and which hut is empty. Do this by asking an appropriate question.


 OK, in which hut is the couple, and which hut is empty?

 Very good, well done!


The Rhob signals an apprentice, who opens the door to the right-hand hut to reveal a man and a woman arm in arm smiling shyly. He subsequently has the door of the other hut opened showing it to be empty.


 Notice, my friend, you received an *appropriate* answer to your question. The couple was indeed in one of the huts. And the other hut was, of course, empty.


 (UNIMPRESSED, YET TRYING TO BE POLITE) Uh huh. Yes, I see.

 But I understand reproducibility is crucial to scientists. We will repeat the experiment.


Six more times this procedure is repeated for our visitor. Sometimes the couple is in the right-hand hut, sometimes in the left. Since our visitor is clearly getting bored, the Rhob stops the demonstrations and explains.

 (SOMEWHAT GLEEFULLY) Notice, my friend! Your asking the whereabouts of the *couple* caused the young man and young woman to be together in a single hut.


 (ANNOYED BY HAVING TRAVELED SO FAR TO SEE AN APPARENTLY TRIVIAL DEMONSTRATION, OUR VISITOR IS FINDING IT HARD NOT TO OFFEND) My *questions* caused the couple to be in one hut or the other? Nonsense! Where you placed them while I was hooded did that. Oh, but, I apologize. Thank you very much for your demonstration. But it's getting late; I must get down the mountain.

 No, it is I who should apologize. I must remember that the attention span of Americans is short. I have heard that you actually choose the leaders of your nation on the basis of a number of thirty-second displays on a small glass wall.

But please, we now have a second experiment. You will ask a different question. You will ask a question causing the man and the woman to be in separate huts.


 Well, yes, but I do have to be down . . .


Without waiting for our visitor to finish, the Rhob hands him the hood, and with a shrug our visitor dons it. And the Rhob speaks.


 Please remove the hood. Ask a *new* question, one to determine in which hut is the man and in which hut is the woman.


 OK, OK, in which hut is the man and in which hut is the woman?


This time the Rhob signals his apprentices to open the huts at the same time. They reveal the man in the right-hand hut and the woman in the left, smiling at each other across the plaza.

 Notice! You received an answer appropriate to the new question you asked, a result appropriate to the *different* experiment you did. Your question caused the couple to be *distributed over both huts*. We now display reproducibility by repeating this experiment.


 Please, I must be leaving. (NOW WITH A SARCASTIC TONE OF VOICE) I concede that your "experiments" are all repeatable an arbitrarily large number of times with equally impressive results.


 Oh, I *am* sorry.


 (TAKEN ABACK BY HIS OWN DISCOURTESY) Oh, no, I apologize. I would be delighted to see a repeat of this experiment.


 Well, maybe just two or three times?

The demonstration is repeated three times.


 You seem impatient. So maybe three times is enough to demonstrate that your asking the whereabouts of the man and the women *separately* caused the couple to be *spread* over both huts. Can you agree?


 (BORED AND DISAPPOINTED, BUT SOMEWHAT SMUG) I surely agree that you can distribute the couple over the huts the way you wish. However, now I truly must be getting down the mountain. But thank you very much for . . .


 (INTERRUPTING) You have not yet seen the *final* version of these experiments. It is the *crucial* one that completes our demonstration. Let me do it for you—just twice. Only two times.

 (CONDESCENDINGLY) Well, OK, two times.

Our visitor again dons the hood.

 Please remove the hood and ask your question.


 Which question should I ask?


 Ah, my friend, you are now experienced with both questions. You may ask either of them. You may choose either experiment.

 (WITHOUT MUCH THOUGHT) OK, in which hut is the couple?

The Rhob has the door of the right-hand hut opened to reveal a man and a woman hand in hand. He then has the door of the other hut opened showing it to be empty.


 (A BIT PUZZLED, BUT NOT REALLY SURPRISED) Hmmm

 Notice the question you asked, the experiment you chose, caused the couple to be in a single hut. Now let's try it again—for the second time—to which you did agree.


 (QUITE WILLINGLY) Sure, let's try again.


Our visitor again dons the hood.


 Please remove the hood and ask either question.


 (WITH A TOUCH OF SKEPTICISM) OK, this time I've decided to ask the other question: In which hut is the man, and in which hut is the woman?

The Rhob has his apprentices open both huts at the same time to reveal the man in the right-hand hut and the woman in the left.


 Hmmmmm. . . . (Aside, a spoken thought) Funny, he was able to answer the question I chose twice in a row. He could not know which one I would ask.


 Notice, my friend, whichever question you choose to ask is always appropriately answered. And now you wish to leave us.

 Well, uh, . . . as a matter of fact, I'd like to try this last experiment again.


 Very well. I am delighted by your interest in the demonstration that no matter which experiment you choose, you always get an appropriate answer.


Our visitor once more dons the hood.


 Please remove the hood and once again, ask either question.


 OK, *this* time, in which hut is the couple?

The Rhob has the door to the left-hand hut opened to reveal the man and woman together. He then has the door of the other hut opened showing it to be empty.


 You had arranged an appropriate answer to the question I later chose to ask three times in a row. Your luck is impressive!


 It was not luck, my friend. The observation you freely chose determined whether the couple would be together in one hut or divided in two.

 (puzzled) How can that be? (eagerly, now) Can we try that again?


 Surely, if you wish.


The demonstration is repeated, and our increasingly puzzled visitor requests yet further repetitions. Eight times he sees a result appropriate to the question he asked, but a result inappropriate to the other question he could have asked.


 (AN AGITATED ASIDE: *I can't believe this!*) Please, I'd like to try this yet again!


 I'm afraid it now is getting dark, and it is a steep climb down the mountain. Be assured that you will always get answers appropriate to the question you ask, appropriate to the situation your question caused to exist.


 (MUMBLES AND LOOKS BOTHERED)


 Something troubles you, my friend?


 How did you know which question I was going to ask when you placed your people in the huts?

 I did not know. You could have asked either question.


 (agitated) But, but . . . let's be reasonable! What if I had asked the question that did *not* correspond to where the man and woman actually were?


 My friend, did not your great Danish physicist, Bohr of Copenhagen, teach that science need not provide explanations for experiments not actually performed, need not answer questions not actually asked?

 Oh yes, but come on. Your people had to be either together or separated immediately before I asked my question.

 I see what disturbs you. In spite of your training as a physicist, and your experience with quantum mechanics in the laboratory, you are still imbued with the notion that a particular physical reality exists before your choice of what to observe, and before your conscious experience of it. Apparently physicists find it hard to fully comprehend the great truth they have so recently gleaned. But good night,

my friend. You have seen what you came to see. You must now leave us. Have a safe trip down the mountain.

 (OBVIOUSLY BAFFLED AS HE TURNS TO LEAVE) Uh, yes, I will, uh, thank you very much, very much, I, uh, well . . . thank you . . .

 (TALKING TO HIMSELF AS HE PICKS HIS WAY DOWN THE STEEP AND ROCKY TRAIL) Now let's see, there's got to be a reasonable explanation. If I asked where the couple was, he immediately showed the couple together in a single hut. But if I chose to ask where the man and woman each were separately, he immediately showed one of them in *each* hut. But before I asked they had to be in one situation or the other? The huts were far apart. How did he do it?!

Was I tricked into asking the question that fit the setup he had arranged? No, I *know* my choices were freely made.

It's impossible! But I saw it. It's like a quantum experiment, where both situations existed at the same time, Until you look you see only one. "Conscious experience," the Rhob said. But physics shouldn't involve anything like *consciousness*! Anyway, quantum mechanics doesn't apply to big things like people. Well . . ., of course, that's not quite right. In principle, quantum physics applies to everything. But you can only demonstrate such stuff with an interference experiment. And interference experiments are impossible with big things—for all practical purposes. Was I hallucinating?

How do I debunk this Rhob when I get back to California? And, oh my god! The guys back in the physics department will ask about my trip. Ouch!

There is, of course, no Neg Ahne Poc. What our visitor saw is in fact impossible. But in later chapters you will see how an object can be shown to be wholly in one place or, by a different choice of experiment, could have been shown to have been distributed over two locations, like the couple in Neg Ahne Poc. You should experience the same bafflement as did our Neg Ahne Poc visitor.

Demonstrating that a physical reality is caused by observation is limited by present technology to very small things. But it's being demonstrated for larger and larger objects all the time. We will devote a whole chapter to

physics' "orthodox" resolution of this paradox, the Copenhagen interpretation of quantum mechanics, with Niels Bohr as its principal architect. The explanation given by Bohr is not unlike that given by the Rhob in Neg Ahne Poc ("Rhob" is Bohr spelled backward.) We later discuss modern challenges to the Copenhagen interpretation.