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THE GOD PARTICLE

ΤΟΥ LEON LEDERMAN

ΜΕ ΤΟΝ DICK TERESI

ΕΙΝΑΙ ΕΝΑΣ ΕΙΚΟΝΙΚΟΣ ΔΙΑΛΟΓΟΣ ΜΕΤΑΞΥ LEDERMAN ΚΑΙ ΔΗΜΟΚΡΙΤΟΥ Ο ΟΠΟΙΟΣ ΓΙΝΕΤΑΙ ΕΝΑ ΒΡΑΔΥ ΣΤΟ ΠΕΙΡΑΜΑ CDF ΣΤΟ FERMILAB ΤΩΝ Η.Π.Α.

Με χιούμορ, χαρακτηριστικό του Leon Lederman, γίνεται μια ανασκόπηση της Φυσικής Φιλοσοφίας των αρχαίων Ελλήνων.

distressed and come to their assistance. (No one to my knowledge has ever tried this, but it should work.)

One of the wonderful (but unverified) stories in physics emphasizes the importance of 137 as well as illustrating the arrogance of theorists. According to this tale, a notable Austrian mathematical physicist of Swiss persuasion, Wolfgang Pauli, went to heaven, we are assured, and, because of his eminence in physics, was given an audience with God.

"Pauli, you're allowed one question. What do you want to know?"

Pauli immediately asked the one question that he had labored in vain to answer for the last decade of his life. "Why is alpha equal to one over one hundred thirty-seven?"

God smiled, picked up the chalk, and began writing equations on the blackboard. After a few minutes, She turned to Pauli, who waved his hand. "Das ist falsch!" [That's baloney!]

There's a true story also — a verifiable story — that takes place here on earth. Pauli was in fact obsessed with 137, and spent countless hours pondering its significance. The number plagued him to the very end. When Pauli's assistant visited the theorist in the hospital room in which he was placed prior to his fatal operation, Pauli instructed the assistant to note the number on the door as he left. The room number was 137.

That's where I lived: 137 Eola Road.

LATE NIGHT WITH LEDERMAN

Returning home one weekend night after a late supper in Batavia, I drove through the lab grounds. From several points on Eola Road, one can see the central lab building lit up against the prairie sky. Wilson Hall at 11:30 on a Sunday night is testimony to how strongly physicists feel about solving the remaining mysteries of the universe. Lights were blazing up and down the sixteen floors of the twin towers, each containing its quota of bleary-eyed researchers trying to work out the kinks in our opaque theories about matter and energy. Fortunately, I could drive home and go to bed. As director of the lab, my night-shift obligations were drastically reduced. I was able to sleep on problems rather than work on them. I was grateful that night to lie on a real bed rather than having to bunk down on the accelerator floor waiting for the data to come in. Nevertheless, I tossed and turned, worrying about quarks, Gina, leptons, Sophia . . . Finally, I resorted to counting sheep to get my mind off physics: ". . . 134, 135, 136, *137* . . ."

Suddenly I rose from between the sheets, a sense of urgency driving me from the house. I pulled my bicycle out of the barn, and — still clad in pajamas, my medals falling from my lapels as I pedaled — I rode in painfully slow motion toward the collider detector facility. It was frustrating. I knew I had some very important business to attend to, but I just couldn't get the bike to move any faster. Then I remembered what a psychologist had told me recently: that there is a kind of dream, called a lucid dream, in which the dreamer knows he is in a dream. Once you know this, said the psychologist, you can do anything you want inside the dream. The first step is to find some clue that you're dreaming and are not in real life. That was easy. I knew damn well this was a dream because of the italics. I hate italics. Too hard to read. I took control of my dream. "No more italics!" I screamed.

There. That's better. I put the bike into high gear and pedaled at light speed (hey, you can do anything in a dream) toward the CDF. Oops, too fast: I had circled the earth eight times and ended up back home. I geared down and pedaled at a gentle 120 miles per hour to the facility. Even at three in the morning the parking lot was fairly full; at accelerator labs the protons don't stop at nightfall.

Whistling a ghostly little tune, I entered the detector facility. The CDF is an industrial hangar–like building, with everything painted bright orange and blue. The various offices, computer rooms, and control rooms are all along one wall; the rest of the building is open space, designed to accommodate the detector, a three-story-tall, 5,000-ton instrument. It took some two hundred physicists and an equal number of engineers more than eight years to assemble this particular 10-million-pound Swiss watch. The detector is multicolored, radial in design, its components extending out symmetrically from a small hole in the center. The detector is the crown jewel of the lab. Without it, we cannot "see" what goes on in the accelerator tube, which passes through the center of the detector's core. What goes on, dead center in the detector, are the head-on collisions of protons and antiprotons. The radial spokes of the detector elements roughly match the radial spray of hundreds of particles produced in the collision.

The detector moves on rails that allow the enormous device to be moved out of the accelerator tunnel to the assembly floor for periodic maintenance. We usually schedule maintenance for the summer months, when electric rates are highest (when your electric bill runs more than $10 million a year, you do what you can to cut costs). On this night the detector was on-line. It had been moved back into the tunnel, and the passageway to the maintenance room had been plugged with a 10-foot-thick steel door that blocks the radiation. The accelerator is so designed that the protons and antiprotons collide (mostly) in the section of pipe that runs through the detector — the "collision region." The job of the detector, obviously, is to detect and catalogue the products of the head-on collisions between protons and p-bars (antiprotons).

Still in my pajamas, I made my way up to the second-floor control room, where the findings of the detector are continuously monitored. The room was quiet, as one would expect at this hour. No welders or other workmen roamed the facility making repairs or performing other maintenance tasks, as is common during the day shift. As usual, the lights in the control room were dim, to better see and read the distinctive bluish glow of dozens of computer monitors. The computers in the CDF control room are Macintoshes, just like the microcomputers you might buy to keep track of your finances or to play Cosmic Ozmo. They are fed information from a humongous "home-built" computer that works in tandem with the detector to sort through the debris created by the collisions between protons and antiprotons. The home-built thing is actually a sophisticated data acquisition system, or DAQ, designed by some of the brightest scientists in the fifteen or so universities around the world that collaborated to build the CDF monster. The DAQ is programmed to decide which of the hundreds of thousands of collisions each second are interesting or important enough to analyze and record on magnetic tape. The Macintoshes monitor the great variety of subsystems that collect data.

I surveyed the room, scanning the numerous empty coffee cups and the small band of young physicists, simultaneously hyper and exhausted, the result of too much caffeine and too many hours on shift. At this hour you find graduate students and young postdocs (new Ph.D.'s), who don't have enough seniority to draw decent shifts. Notable was the number of young women, a rare commodity in most physics labs. CDF's aggressive recruiting has paid off to the pleasure and profit of the group.

Over in the corner sat a man who didn't quite fit in. He was thin with a scruffy beard. He didn't look that different from the other researchers, but somehow I knew he wasn't a member of the staff. Maybe it was the toga. He sat staring into the Macintosh, giggling nervously. Imagine, laughing in the CDF control room! At one of the greatest experiments science has ever devised! I thought I'd better put my foot down.

LEDERMAN: Excuse me. Are you the new mathematician they were supposed to send over from the University of Chicago?

GUY IN TOGA: Right profession, wrong town. Name's Democritus. I hail from Abdera, not Chicago. They call me the Laughing Philosopher.

LEDERMAN: Abdera?

DEMOCRITUS: Town in Thrace, on the Greek mainland.

LEDERMAN: I don't remember requisitioning anyone from Thrace. We don't need a Laughing Philosopher. At Fermilab I tell all the jokes.

DEMOCRITUS: Yes, I've heard of the Laughing Director. Don't worry about it. I doubt if I'll be here long. Not given what I've seen so far.

LEDERMAN: So why are you taking up space in the control room?

DEMOCRITUS: I'm looking for something. Something very small.

LEDERMAN: You've come to the right place. Small is our specialty.

DEMOCRITUS: So I'm told. I've been looking for this thing for twenty-four hundred years.

LEDERMAN: Oh, you're *that* Democritus.

DEMOCRITUS: You know another one?

LEDERMAN: I get it. You're like the angel Clarence in *It's a Wonderful Life,* sent here to talk me out of suicide. Actually, I *was* thinking about slicing my wrists. We can't find the top quark.

DEMOCRITUS: Suicide! You remind me of Socrates. No, I'm no angel. That immortality concept came after my time, popularized by that softhead Plato.

LEDERMAN: But if you're not immortal, how can you be here? You died over two millennia ago.

DEMOCRITUS: There are more things in heaven and earth, Horatio, than are dreamt of in your philosophy.

LEDERMAN: Sounds familiar.

DEMOCRITUS: Borrowed it from a guy I met in the sixteenth century. But to answer your question, I'm doing what you call time traveling.

LEDERMAN: Time traveling? You figured out time travel in fifth-century-B.C. Greece?

DEMOCRITUS: Time is a piece of cake. It goes forward, it goes backward. You ride it in and out, like your California surfers. It's matter that's hard to figure. Why, we even sent some of our graduate students to your era. One, Stephenius Hawking, made quite a stir, I've heard. He specialized in "time." We taught him everything he knows.

LEDERMAN: Why didn't you publish this discovery?

DEMOCRITUS: Publish? I wrote sixty-seven books and would have sold a bunch, but the publisher just refused to advertise. Most of what you know about me you know through Aristotle's writings. But let me fill you in a little. I traveled — boy, did I travel! I covered more territory than any man in my time, making the most extensive investigations, and saw more climes and countries, and listened to more famous men . . .

LEDERMAN: But Plato hated your guts. Is it true he disliked your ideas so much that he wanted all your books burned?

DEMOCRITUS: Yes, and that superstitious old goat nearly succeeded. And then that fire in Alexandria really cooked my reputation. That's why you so-called moderns are so ignorant of time manipulation. Now all I hear about is Newton, Einstein . . .

LEDERMAN: So why this visit to Batavia in the 1990s?

DEMOCRITUS: Just checking up on one of my ideas, an idea that was unfortunately abandoned by my countrymen.

LEDERMAN: I bet you're speaking of the atom, the *atomos*.

DEMOCRITUS: Yes, the a-tom, the ultimate, indivisible, and invisible particle. The building block of all matter. I've been jumping ahead through time, to see how far man has come with refining my theory.

LEDERMAN: And your theory was . . .

DEMOCRITUS: You're baiting me, young man! You know very well what I believed. Don't forget, I've been time-hopping century by century, decade by decade. I'm well aware that the nineteenth-century chemists and the twentieth-century physicists have been playing around with my ideas. Don't get me wrong — you were right to do so. If only Plato had been as wise.

LEDERMAN: I just wanted to hear it in your own words. We know of your work primarily through the writings of others.

DEMOCRITUS: Very well. Here we go for the umpteenth time. If I sound bored, it's because I recently went through this with that fellow Oppenheimer. Just don't interrupt me with tedious musings about the parallels between physics and Hinduism.

LEDERMAN: Would you like to hear my theory about the role of Chinese food in mirror-symmetry violation? It's as valid as saying the world is made of air, earth, fire, and water.

DEMOCRITUS: Why don't you just keep quiet and let me start from the beginning. Here, take a seat next to this Macintosh thing and pay attention. Now, if you're going to understand my work, and the work of all of us atomists, we have to go back twenty-six hundred years. We have to start about two hundred years before I was born, with Thales, who flourished around 600 B.C. in Miletus, a hick town in Ionia, which you now call Turkey.

LEDERMAN: Thales was a philosopher, too?

DEMOCRITUS: And how! He was the *first* Greek philosopher. But philosophers in pre-Socratic Greece really knew a lot of things. Thales was an accomplished mathematician and astronomer. He sharpened his training in Egypt and Mesopotamia. Did you know he predicted an eclipse of the sun that occurred at the close of the war between the Lydians and Medes? He constructed one of the first almanacs — I understand you leave this task to farmers today — and he taught our sailors how to steer a ship at night by using the Little Bear constellation. He was also a political adviser, a shrewd businessman, and a fine engineer. Early Greek philosophers were respected not only for the aesthetic workings of their minds but also for their practical arts, or applied science, as you would put it. Is it any different today with physicists?

LEDERMAN: We have been known to do something useful now and then. But I'm sorry to say that our achievements are usually very narrowly focused, and very few of us know Greek.

DEMOCRITUS: Lucky for you I speak English then, yes? Anyhow, Thales, like me, kept asking himself a primary question: "What is the world made of, and how does it work?" Around us we see apparent chaos. Flowers bloom, then die. Floods destroy the land. Lakes become deserts. Meteors fall out of the sky. Whirlwinds appear apparently out of nowhere. From time to time a mountain explodes. Men grow old and turn to dust. Is there something permanent, an underlying identity, that persists through this constant change? Can all of this be reduced to rules so simple that our small minds can understand?

LEDERMAN: Did Thales come up with an answer?

DEMOCRITUS: Water. Thales said water was the primary and ultimate element.

LEDERMAN: How did he figure?

DEMOCRITUS: It's not such a crazy idea. I'm not totally sure what Thales was thinking. But consider: water is essential to growth, at least among plants. Seeds have a moist nature. Almost anything gives off water when heated. And water is the only substance known that can exist as solid, liquid, or gas — as water vapor or steam. Maybe he figured water could be transformed into earth if this process were carried further. I don't know. But Thales made a very great beginning for what you call science.

LEDERMAN: Not bad for a first try.

DEMOCRITUS: The impression around the Aegean is that Thales and his group were given a bad rap by the historians, especially Aristotle. Aristotle was obsessed by forces, by causation. You can hardly talk to him about anything else, and he picked on Thales and his friends in Miletus. Why water? And what force causes the change from rigid water to aethereal water? Why so many different forms of water?

LEDERMAN: In modern physics, er, in the physics of these times, forces are required in addition to —

DEMOCRITUS: Thales and his crowd may well have enmeshed the notion of cause into the very nature of his water-based matter. Force and matter unified! Let's save that for later. Then you can tell me about things you call gluons and supersymmetry and —

LEDERMAN [*frantically scratching his goose bumps*]: Uh, what else did this genius do?

DEMOCRITUS: He had some conventionally mystical ideas. He believed the earth floated on water. He believed that magnets have souls because they can move iron. But he believed in simplicity, that there is a unity to the universe, even though there are many varied material "things" around us. Thales combined a set of rational arguments with whatever mythological hangovers he had in order to give water a special role.

LEDERMAN: I suppose Thales believed the world was being carried by Atlas standing on a turtle.

DEMOCRITUS: Au contraire. Thales and his pals had this very important meeting, probably in the back room of a restaurant in downtown Miletus. After a certain quantity of Egyptian wine, they threw out Atlas and made a solemn agreement: "From this day forth, explanations and theories of how the world works will be based strictly upon logical arguments. No more superstition. No more appeals to Athena, Zeus, Hercules, Ra, Buddha, Lao-tzu. Let's see if we can find out for ourselves." This may have been the most important agreement ever made by humans. It was 650 B.C., probably a Thursday night, and it was the birth of science.

LEDERMAN: Do you think we've gotten rid of superstition now? Have you met our creationists? Our animal rights extremists?

DEMOCRITUS: Here at Fermilab?

LEDERMAN: No, but not far away. But tell me, when did this earth, air, fire, and water idea come in?

DEMOCRITUS: Hold your horses. There were a couple of other guys before we get to that theory. Anaximander, for one. He was a young associate of Thales' in Miletus. Anaximander also earned his spurs doing practical things, such as constructing a map of the Black Sea for Milesian sailors. Like Thales, he sought a primary building block of matter, but he decided it couldn't be water.

LEDERMAN: Another great advance in Greek thinking, no doubt. What was *his* candidate, baklava?

DEMOCRITUS: Have your laugh. We'll get to *your* theories soon enough. Anaximander was another practical genius and, like his mentor Thales, he used his spare time to join in the philosophical debate. Anaximander's logic was fairly subtle. He saw the world as being composed of warring opposites — hot and cold, wet and dry. Water puts out fire; the sun dries up water, et cetera. Therefore the primary substance of the universe cannot be water or fire or anything characterized by one of these opposites. No symmetry there. And you know how we Greeks loved symmetry. For example, if all matter was originally water, as Thales said, then heat or fire could never come into being, since water does not generate fire but obliterates it.

LEDERMAN: Then what *did* he propose as the primary substance?

DEMOCRITUS: He called it the *apeiron*, meaning "without boundaries." This first state of matter was an undifferentiated mass of enormous, possibly infinite, proportions. It was the primitive "stuff," neutral between opposites. This idea had a deep influence on my own thinking.

LEDERMAN: So this apeiron was something like your a-tom — except that it was an infinite substance as opposed to an infinitesimal particle? Didn't this just confuse things?

DEMOCRITUS: No, Anaximander was on to something. The apeiron was infinite, both in space and time, but it was also structureless; it had no component parts. It was nothing but apeiron through and through. And if you're going to decide on a primary substance, it had better have this quality. In fact, my point is to embarrass you by noting that after two thousand years, you are finally coming around to appreciating the prescience of my crowd. What Anaximander did was to invent the vacuum. I think your P. A. M. Dirac finally began to give the vacuum the properties it deserved in the 1920s. Anaxi's apeiron was the prototype of my own "void," a nothingness in which particles move. Isaac Newton and James Clerk Maxwell called it aether.

LEDERMAN: But what about the stuff, matter?

DEMOCRITUS: Listen to this [*pulls a parchment roll out of his toga, perches a pair of discount MagnaVision reading glasses on his nose*]: Anaximander says, "It is neither water nor any other of the so-called elements, but a different substance which is boundless, from which they come into being all the heavens and the worlds within them. Things perish into those things out of which they have their being . . . opposites are in the one and separated out." Now, I know you twentieth-century types are always talking about matter and antimatter created in the vacuum, also annihilating . . .

LEDERMAN: Sure, but . . .

DEMOCRITUS: When Anaximander says opposites were in the apeiron — call it a vacuum, or call it the aether — and were separated out, isn't that something like what you think?

LEDERMAN: Sort of, but I'm much more interested in what made Anaximander think these things.

DEMOCRITUS: Of course he didn't anticipate antimatter. But in a properly endowed vacuum, he thought that opposites could separate: hot and cold, wet and dry, sweet and sour. Today you add positive and negative, north and south. When they combine, they cancel their properties into the neutral apeiron. Isn't that neat?

LEDERMAN: How about democrat and republican? Was there a Greek named Republicas?

DEMOCRITUS: Very amusing. At least Anaximander attempted to explain the mechanism that creates diversity out of a primary element. And his theory led to a number of sub-beliefs, some of which you might even agree with. Anaximander believed, for example, that man evolved from lower animals, which in turn were descended from creatures in the sea. His greatest cosmological idea was to get rid of not only Atlas but even Thales' ocean that held up the earth. He knew you didn't need to hold up the earth. Picture the thing (not yet given spherical shape) suspended in infinite space. There is no place to go. Totally in accord with Newton's laws if, as these Greeks thought, there was nothing else. Anaximander also figured there had to be more than one world, or universe. In fact, he said there were an unlimited number of universes, all perishable, following one another in succession.

LEDERMAN: Like alternate universes on "Star Trek"?

DEMOCRITUS: Hold your commercials. The idea of innumerable worlds became very important to us atomists.

LEDERMAN: Wait a minute. I'm remembering something you wrote that gave me shivers in light of modern cosmology. I even memorized it. Let's see: "There are innumerable worlds of different sizes. In some there is neither sun nor moon, in others they are larger than in ours, and other worlds have more than one sun and more than one moon."

DEMOCRITUS: Yes, we Greeks held some ideas in common with your Captain Kirk. But we dressed a lot better. I'd rather compare my idea to the bubble universes that your inflationary cosmologists are publishing papers on these days.

LEDERMAN: That's really why I got spooked. Didn't one of your predecessors believe that air was the ultimate element?

DEMOCRITUS: You're thinking of Anaximenes, a younger associate of Anaximander's and the last of the Thales gang. He actually took a step backward from Anaximander and said there was a common primordial element, as Thales did — except Anaximenes said this element was air, not water.

LEDERMAN: He should have listened to his mentor; then he would have ruled out anything as mundane as air.

DEMOCRITUS: Yes, but Anaximenes did come up with a clever mechanism for explaining how various forms of matter are transformed from this primary substance. I understand from my readings that you're one of those experimentalists.

LEDERMAN: Yeah. You got a problem with that?

DEMOCRITUS: I've noticed your sarcasm toward so much of Greek theory. I suspect your prejudice comes from the fact that many of these ideas, while plausibly suggested by the world around us, do not lend themselves to incisive experimental verification.

LEDERMAN: True. Experimenters dearly love ideas that can be verified. It's how we make a living.

DEMOCRITUS: Then you may have more respect for Anaximenes, since his beliefs were based on observation. He theorized that the various elements of matter were separated out of air via condensation and rarefaction. Air can be reduced to moisture and vice versa. Heat and cold transform air into different substances. To demonstrate how heat is connected to rarefaction and cold to condensation, Anaximenes advised people to conduct this experiment: breathe out with your lips nearly closed, and the air will emerge cold. But if you open your mouth wide, your breath will be warmer.

LEDERMAN: Congress would love Anaximenes. His experiments are cheaper than mine. And all that hot air . . .

DEMOCRITUS: I get it, but I wanted to dispel your idea that we ancient Greeks never did any experiments. The main problem with thinkers such as Thales and Anaximenes was their belief that substances can be transformed: water can become earth; air can become fire. Can't happen. This snag in our early philosophy wasn't really addressed until two of my contemporaries came along— Parmenides and Empedocles.

LEDERMAN: Empedocles is the earth, air, et cetera guy, right? Remind me about Parmenides.

DEMOCRITUS: He is often called the father of idealism, since much of his thought was picked up by that idiot Plato, but in fact he was a hard-core materialist. He talked a lot about Being, but this Being was material. Essentially, Parmenides held that Being can neither come to be nor pass away. Matter doesn't just pop in and out of existence. It's there and we can't destroy it.

LEDERMAN: Let's go down to the accelerator and I'll show you how wrong he is. We pop matter in and out of existence all the time.

DEMOCRITUS: Okay, okay. But this is an important concept. Parmenides was embracing an idea that was dear to us Greeks: oneness. Wholeness. What exists, exists. It is complete and enduring. I suspect you and your colleagues also embrace unity.

LEDERMAN: Yes, it's an enduring and endearing concept. We strive for unity in our beliefs whenever we can. Grand Unification is one of our current obsessions.

DEMOCRITUS: And, in fact, you don't just pop new matter into existence by will alone. I believe you have to add energy to the process.

LEDERMAN: True, and I have the electric bill to prove it.

DEMOCRITUS: So, in a way, Parmenides wasn't that far off. If you include both matter and energy in what he calls Being, then he's right. It can neither come to be nor pass away, at least not in a total sort of way. And yet our senses tell another story. We see trees burn to the ground. The fire can then be destroyed by water. The hot air of summer can evaporate the water. Flowers appear, then die. It was Empedocles who saw a way around this apparent contradiction. He agreed with Parmenides that matter must be conserved, that it cannot appear or disappear willy-nilly. But he disagreed with Thales and Anaximenes that one kind of matter can become another. How, then, does one account for the constant change one sees around us? There are only four kinds of matter, said Empedocles. His famous earth, air, fire, and water. They do not change into other types of matter, but are unchangeable and ultimate *particles*, which form the concrete objects of the world.

LEDERMAN: Now you're talking.

DEMOCRITUS: Thought you'd like that. Objects come into being through the mingling of these elements, and they cease to be through the separation of elements. But the elements themselves — earth, air, fire, water — neither come into being nor pass away but remain unchanged. Obviously I disagree with him as to the identity of these particles, but in principle he made an important intellectual leap. There are only a few basic ingredients in the world, and you construct objects by mixing them together in a multitude of ways. For example, Empedocles said that bone is composed of two parts earth, two parts water, and four parts fire. How he came up with this recipe escapes me at the moment.

LEDERMAN: We tried the air-earth-fire-water mixture and all we got was hot, bubbling mud.

DEMOCRITUS: Leave it to a "modern" to bring the discussion down a notch.

LEDERMAN: What about forces? None of you Greeks seem to realize you need forces as well as particles.

DEMOCRITUS: I have my doubts, but Empedocles would agree. He saw that you needed forces to fuse these elements into other objects. He came up with two: love and strife — love to draw things together, strife to separate them. Not very scientific, perhaps, but don't the scientists in your age have a similar system of beliefs for the universe? A number of particles and a set of forces? Often given whimsical names?

LEDERMAN: In a way, yes. We have what we call the "standard model." It holds that everything we know about the universe can be explained by the interactions of a dozen particles and four forces.

DEMOCRITUS: There you go. Empedocles' world view doesn't sound all that different, does it? He said the universe could be explained with four particles and two forces. You've just added a couple more, but the structure of both models is similar, no?

LEDERMAN: Sure, but we don't go along with the content: fire, earth, strife . . .

DEMOCRITUS: Well, I suppose you have to show something for two thousand years of hard work. But, no, I don't hold with the content of Empedocles' theory either.

LEDERMAN: Then what do you believe in?

DEMOCRITUS: Ah, now we get down to business. The work of Parmenides and Empedocles set the stage for my own work. I believe in the a-tom, or atom, that which cannot be cut. The atom is the building block of the universe. All of matter is composed of various arrangements of atoms. It is the smallest thing in the universe.

LEDERMAN: You had the instruments necessary to find invisible objects in fifth-century-B.C. Greece?

DEMOCRITUS: Not exactly "find."

LEDERMAN: Then what?

DEMOCRITUS: Perhaps "discover" is a better word. I discovered the atom through Pure Reason.

LEDERMAN: What you're saying is that you just thought about it. You didn't bother to do any experiments.

DEMOCRITUS [*gesturing to indicate the far reaches of the laboratory*]: There are some experiments that the mind can do better than even the largest, most precise instrument.

LEDERMAN: What gave you the idea of atoms? It was, I must admit, a brilliant hypothesis. But it goes way beyond what went before.

DEMOCRITUS: Bread.

LEDERMAN: Bread? Someone paid you to come up with the idea?

DEMOCRITUS: Not that kind of bread. This was in the era before federal grants. I mean real bread. One day, during a prolonged fast, someone walked into my study carrying a loaf of bread just out of the oven. I knew it was bread before I saw it. I thought: some invisible essence of bread traveled ahead and reached my Grecian nose. I made a note about odors and thought about other "traveling essences." A small pool of water shrinks and eventually dries up. Why? How? Can invisible essences of water leap out of the pool and travel long distances like my warm bread? Lots of little things like that — you see, you think, you talk about it. My friend Leucippus and I argued for days and days, sometimes until the sun rose and our wives came after us with clubs. We finally decided that if each substance was made of atoms, invisible because they were too small for our human eyes, we would have too many different types: water atoms, iron atoms, daisy petal atoms, bee foreleg atoms — a system so ugly as to be un-Greek.

Then we got a better idea. Have only a few different styles of atoms, like smooth, rough, round, angular, and have a selected number of different shapes, but have an infinite supply of each kind. Then put them in empty space. (Boy, you should have seen all the beer we drank to understand empty space! How do you define "nothing at all"?) Let these atoms move about at random. Let them move incessantly, occasionally colliding, sometimes sticking and collecting together. Then one collection of atoms makes wine, another makes the glass in which it is served, ditto feta cheese, baklava, and olives.

LEDERMAN: Didn't Aristotle argue that these atoms should naturally fall?

DEMOCRITUS: That's his problem. Ever watch motes of dust dancing in a beam of sunlight that enters a darkened room? The dust moves in any and all directions, just like atoms.

LEDERMAN: How did you imagine the *indivisibility* of atoms?

DEMOCRITUS: It took place in the mind. Imagine a knife of polished bronze. We ask our servant to spend his entire day honing the edge until it can sever a blade of grass held at its distant end. Finally satisfied, I begin to act. I take a piece of cheese . . .

LEDERMAN: Feta?

DEMOCRITUS: Of course. Then I cut the cheese in two with the knife. Then again and again, until I have a speck of cheese too small to hold. Now I think that if I myself were much smaller, the speck would appear large to me, and I could hold it, and with my knife honed even sharper, cut it again and again. Now I must again, in my mind, reduce myself to the size of a pimple on an ant's nose. I continue cutting the cheese. If I repeat the process enough, do you know what the result will be?

LEDERMAN: Sure, a feta-compli.

DEMOCRITUS [*groans*]: Even the Laughing Philosopher chokes on a lousy pun. If I may continue . . . Eventually I will come to a piece of stuff so hard that it can never be cut, even given enough servants to sharpen the knife for a hundred years. I believe the smallest object cannot be cut as a matter of necessity. It is unthinkable that we can continue to cut forever, as some so-called learned philosophers say. Now I have the ultimate uncuttable object, the atomos.

LEDERMAN: And you came up with this idea in fifth-century-B.C. Greece?

DEMOCRITUS: Yes, why? Your ideas today are so much different?

LEDERMAN: Well, actually, they're pretty much the same. It's just that we hate the fact that you published first.

DEMOCRITUS: However, what you scientists call the atom is not what I had in mind.

LEDERMAN: Oh, that's the fault of some nineteenth-century chemists. No, nobody today believes the atoms on the periodic table of the elements — hydrogen, oxygen, carbon, et cetera — are indivisible objects. Those guys jumped the gun. They thought they had found your atoms. But they were still many cuts away from the ultimate cheese.

DEMOCRITUS: And today you have found it?

LEDERMAN: Found *them*. There's more than one.

DEMOCRITUS: Well, of course. Leucippus and I believed there were many.

LEDERMAN: I thought Leucippus didn't really exist.

DEMOCRITUS: Tell that to Mrs. Leucippus. Oh, I know some scholars think he was a fictitious figure. But he was as real as this Macintosh thing [*thumps top of computer*], whatever it is. Leucippus was from Miletus, like Thales and the others. And we worked out our atomic theory together, so it's hard to remember who came up with what. Just because he was a few years older, people say he was my teacher.

LEDERMAN: But it was *you* who insisted there were many atoms.

DEMOCRITUS: Yes, that I remember. There are an infinite number of indivisible units. They differ in size and shape, but beyond that they have no real quality other than solidity, impenetrability.

LEDERMAN: They have shape but are otherwise structureless.

DEMOCRITUS: Yes, that's a good way of putting it.

LEDERMAN: So, in your standard model, as it were, how did you relate the qualities of atoms to the stuff they made?

DEMOCRITUS: Well, it's not quite so specific. We figured out that sweet things, for example, are made of smooth atoms, while bitter things are made of sharp atoms. We know that because they hurt the tongue. Liquids are made up of round atoms, while metal atoms have little locks to hold them together. That's why metals are so hard. Fire is composed of small, spherical atoms, as is the soul of man. As Parmenides and Empedocles theorized, nothing real can be born or destroyed. The objects we see around us change constantly, but that's because they are made of atoms, which can assemble and disassemble.

LEDERMAN: How does this assembling and disassembling happen?

DEMOCRITUS: The atoms are in constant motion. Sometimes they combine when they happen to have shapes that are capable of interlocking. And this creates objects large enough to see: trees, water, dolmades. This constant motion can also lead to atoms detaching themselves and to the apparent change in matter we see around us.

LEDERMAN: But new matter, in terms of atoms, is neither created nor destroyed?

DEMOCRITUS: No. That is an illusion.

LEDERMAN: If all substance is created of these essentially featureless atoms, why are objects so different? Why are rocks hard, for instance, and sheep soft?

DEMOCRITUS: Easy. Hard things have less empty space in them. The atoms are packed tighter. Soft things have more space.

LEDERMAN: So you Greeks accepted the concept of space. The void.

DEMOCRITUS: Sure. My partner Leucippus and I invented the atom. Then we needed someplace to put it. Leucippus got himself all tied up in knots (and a little drunk) trying to define the empty space in which we could put our atoms. If it is empty, it is nothing, and how can you define nothing? Parmenides had ironclad proof that empty space cannot exist. We finally decided his proof didn't exist. [*Chuckle.*] Heck of a problem. Took a lot of retsina. During the time of air-earth-fire-water, the void was considered the fifth essence — quintessential is your word. It gave us quite a problem. You moderns accept nothingness unflinchingly?

LEDERMAN: One has to. Nothing works without, well, nothing. But even today it's a difficult and complex concept. However, as you reminded us, our "nothing," the vacuum, is constantly filling up with theoretical concepts: aether, radiation, a negative energy sea, Higgs. Like attic storage space. I don't know what we'd do without it.

DEMOCRITUS: You can imagine how difficult it was in 420 B.C. to explain the void. Parmenides had denied the reality of empty space. Leucippus was the first to say there could be no motion without a void, therefore a void had to exist. But Empedocles had a clever retort that fooled people for a time. He said that motion could take place without empty space. Look at a fish swimming through the ocean, he said. The water parts for the fish's head, then instantaneously moves into the space left by the moving fish at the tail. The two, fish and water, are always in contact. Forget about empty space.

LEDERMAN: And people bought this argument?

DEMOCRITUS: Empedocles was a bright man, and he had effectively demolished void arguments before. The Pythagoreans, for example — contemporaries of Empedocles — accepted the void for the obvious reason that units had to be kept apart.

LEDERMAN: Weren't they the philosophers who refused to eat beans?

DEMOCRITUS: Yes, and that's not such a bad idea in any era. They had some other trivial beliefs, like you shouldn't sit on a bushel or stand on your own toenail clippings. But they also did some interesting things with math and geometry, as you well know. On this void business, though, Empedocles had them because they said the void is filled with air. Empedocles destroyed this argument simply by showing that air was corporeal.

LEDERMAN: So how did you come to accept the void? You had respect for the thinking of Empedocles, no?

DEMOCRITUS: Indeed, and this point defeated me for a long time. I have trouble with emptiness. How do I describe it? If it is truly nothing, then how can it exist? My hands touch your desk here. On the way to the desk top, my palm feels the gentle rush of air that fills the void between me and the desk's surface. Yet air cannot be the void itself, as Empedocles so ably pointed out. How can I imagine my atoms if I cannot feel the void in which they must move? And yet, if I want to somehow account for the world by atoms, I must first define something that seems to be undefinable because it is devoid of properties.

LEDERMAN: So what did you do?

DEMOCRITUS [*laughing*]: I decided not to worry. I a-voided the issue.

LEDERMAN: Oi Vay!

DEMOCRITUS: Σορρψ. [Sorry.] Seriously, I solved the problem with my knife.

LEDERMAN: Your imaginary knife that cuts cheese into atoms?

DEMOCRITUS: No, a real knife, cutting, say, a real apple. The blade must find empty places where it can penetrate.

LEDERMAN: What if the apple is composed of solid atoms, packed together with no space?

DEMOCRITUS: Then it would be impenetrable, because atoms are impenetrable. No, all matter that we can see and feel is cuttable if you have a sharp enough blade. Therefore the void exists. But mostly I said to myself back then, and I believe it still, that one must not forever be stalled by logical impasses. We go on, we continue as if nothingness can be accepted. This will be an important exercise if we are to continue to search for a key to how everything works. We must be prepared to risk falls as we pick our way along the knife edge of logic. I suppose you modern experimentalists would be shocked by this attitude. You need to prove each and every point in order to progress.

LEDERMAN: No, your approach is very modern. We do the same thing. We make assumptions, or we'd never get anywhere. Sometimes we even pay attention to what theorists say. And we have been known to bypass puzzles, leaving them for future physicists to solve.

DEMOCRITUS: You're starting to make some sense.

LEDERMAN: So, to sum up, your universe is quite simple.

DEMOCRITUS: Nothing exists except atoms and empty space; everything else is opinion.

LEDERMAN: If you've figured it all out, why are you here, at the tail end of the twentieth century?

DEMOCRITUS: As I said, I've been time-hopping to see when and if the opinions of man finally coincide with reality. I know that my countrymen rejected the a-tom, the ultimate particle. I understand that people in 1993 not only accept it but believe they have found it.

LEDERMAN: Yes and no. We believe there is an ultimate particle, but not quite the way you said.

DEMOCRITUS: How so?

LEDERMAN: First of all, while you believe in the a-tom as the essential building block, you actually believe there are many kinds of a-toms: liquids have round a-toms; a-toms for metals have locks; smooth a-toms form sugar and other sweet things; sharp a-toms make up lemons, sour stuff. Et cetera.

DEMOCRITUS: And your point is?

LEDERMAN: Too complicated. Our a-tom is much simpler. In your model there would be too large a variety of a-toms. You might as well have one for each type of substance. We hope to find but one single "a-tom."

DEMOCRITUS: I admire such a quest for simplicity, but how could such a model work? How do you get variety from one a-tom, and just what is this a-tom?

LEDERMAN: At this stage we have a small number of a-toms. We call one type of a-tom "quark" and another type "lepton," and we recognize six forms of each type.

DEMOCRITUS: How are they like my a-tom?

LEDERMAN: They are indivisible, solid, structureless. They are invisible. They are . . . small.

DEMOCRITUS: How small?

LEDERMAN: We think the quark is pointlike. It has no dimension, and, unlike your a-tom, it therefore has no shape.

DEMOCRITUS: No dimension? Yet it exists, it is solid?

LEDERMAN: We believe it to be a mathematical point, and then the issue of its solidity is moot. The apparent solidity of matter depends on the details of how quarks combine with one another and with leptons.

DEMOCRITUS: This is hard to think about. But give me time. I do understand your theoretical problem here. I believe I can accept this quark, this substance with no dimension. However, how can you explain the variety of the world around us — trees and geese and Macintoshes — with so few particles?

LEDERMAN: The quarks and leptons combine to make everything else in the universe. And we have six of each. We can make billions of different things with just two quarks and one lepton. For a while we thought that was all one needed. But nature wants more.

DEMOCRITUS: I agree that twelve particles is a lot simpler than my numerous a-toms, but twelve is still a large number.

LEDERMAN: The six kinds of quarks are perhaps different manifestations of the same thing. We say there are six "flavors" of quarks. What this allows us to do is to combine the various quarks to make up all sorts of matter. But one doesn't have to have a separate flavor of quark for each type of object in the universe — one for fire, one for oxygen, one for lead — as is necessary in your model.

DEMOCRITUS: How do these quarks combine?

LEDERMAN: There is a strong force between quarks, a very curious kind of force that behaves very differently from the electrical forces, which are also involved.

DEMOCRITUS: Yes, I know about this electricity business. I had a brief talk with that Faraday fellow back in the nineteenth century.

LEDERMAN: A brilliant scientist.

DEMOCRITUS: Perhaps so, but his math was terrible. He would never have made it in Egypt, where I studied. But I digress. You say a strong force. Are you referring to this gravitational force I've heard about?

LEDERMAN: Gravity? Much too weak. The quarks are actually held together by particles we call gluons.

DEMOCRITUS: Ah, your gluons. Now we're talking about a whole new kind of particle. I thought the quarks were it, that they made matter.

LEDERMAN: They do. But don't forget about forces. There are also particles we call gauge bosons. These bosons have a mission. Their job is to carry information about the force from particle A to particle B and back again to A. Otherwise, how would B know that A is exerting a force on it?

DEMOCRITUS: Wow! Eureka! What a Grecian idea! Thales would love it.

LEDERMAN: The gauge bosons or force carriers or, as we call them, mediators of the force have properties — mass, spin, charge — which in fact determine the behavior of the force. So, for example, the photons, which carry the electromagnetic force, have zero mass, enabling them to travel very fast. This indicates that the force has a very long reach. The strong force, carried by zero-mass gluons, also reaches out to infinity, but the force is so strong that quarks can never get very far from one another. The heavy W and Z particles, which carry what we call the weak force, have a short reach. They work only over very tiny distances. We have a particle for gravity, which we have named the "graviton," even though we have yet to see one or even write down a good theory for one.

DEMOCRITUS: And this is what you call "simpler" than my model?

LEDERMAN: How did you atomists account for the various forces?

DEMOCRITUS: We didn't. Leucippus and I knew that the atoms had to be in constant motion, and we simply accepted this idea. We gave no reason why the world should originally have this restless atomic motion, except perhaps in the Milesian sense that the cause of motion is part of the attribute of the atom. The world is what it is, and one has to accept certain basic characteristics. With all your theories about the four different forces, can you disagree with this idea?

LEDERMAN: Not really. But does this mean that the atomists believed strongly in fate, or chance?

DEMOCRITUS: Everything existing in the universe is the fruit of chance and necessity.

LEDERMAN: Chance and necessity — two opposing concepts.

DEMOCRITUS: Nevertheless, nature obeys them both. It is true that a poppy seed always gives rise to a poppy, never a thistle. That's necessity at work. But the number of poppy seeds formed by the collisions of atoms may well have strong elements of chance.

LEDERMAN: What you're saying is that nature deals us a particular poker hand, which is a matter of chance. But that hand has necessary consequences.

DEMOCRITUS: A vulgar simile, but yes, that's the way it works. This is so alien to you?

LEDERMAN: No, what you've just described is something like one of the fundamental beliefs of modern physics. We call it quantum theory.

DEMOCRITUS: Oh yes, those young Turks in the nineteen-twenties and thirties. I didn't tarry in that era for long. All those fights with that Einstein fellow — never did make much sense to me.

LEDERMAN: You didn't enjoy those wonderful debates between the quantum cabal — Niels Bohr, Werner Heisenberg, Max Born, and their crowd — and such physicists as Erwin Schrödinger and Albert Einstein, who argued against the idea of chance determining nature's way?

DEMOCRITUS: Don't get me wrong. Brilliant men, all of them. But their arguments always concluded with one party or the other bringing up the name of God and Her supposed motivations.

LEDERMAN: Einstein said he couldn't accept that God plays dice with the universe.

DEMOCRITUS: Yes, they always pull the God trump card when the debate goes poorly. Believe me, I had enough of that in ancient Greece. Even my defender Aristotle raked me over the coals for my beliefs in chance and for accepting motion as a given.

LEDERMAN: How did you like quantum theory?

DEMOCRITUS: Definitely I liked it, I think. Later I met Richard Feynman, and he confided that he had never understood quantum theory either. I always had trouble with . . . Wait a minute! You've changed the subject. Let's get back to those "simple" particles you were prattling about. You were explaining how the quarks stick together to make up . . . to make what?

LEDERMAN: Quarks are building blocks of a large class of objects that we call hadrons. This is a Greek word meaning "heavy."

DEMOCRITUS: Really!

LEDERMAN: It's the least we can do. The most famous object made of quarks is the proton. It takes three quarks to make a proton. In fact, it takes three quarks to make the many cousins of the proton, but with six different quarks, there are plenty of combinations of three quarks — I think it's two hundred sixteen. Most of these hadrons have been discovered and given Greek-letter names like lambda (Λ), sigma (Σ), et cetera.

DEMOCRITUS: The proton is one of these hadrons?

LEDERMAN: And the most popular in our present universe. You can stick three quarks together to get a proton or a neutron, for instance. Then you can make an atom by adding an electron, which belongs to the class of particles called leptons, to one proton. That particular atom is called hydrogen. With eight protons and an equal number of neutrons and eight electrons you can build an oxygen atom. The neutrons and protons huddle together in a tiny clump that we call the nucleus. Stick two hydrogen atoms and one oxygen atom together and you get water. A little water, a little carbon, some oxygen, a few nitrogens, and sooner or later you have gnats, horses, and Greeks.

DEMOCRITUS: And it all starts with quarks.

LEDERMAN: Yup.

DEMOCRITUS: And that's all you need.

LEDERMAN: Not exactly. You need something that allows atoms to stay together and then to stick to other atoms.

DEMOCRITUS: The gluons again.

LEDERMAN: No, they only stick quarks together.

DEMOCRITUS: Γοοδ γριεφ! [Good grief!]

LEDERMAN: That's where Faraday and the other electricians, such as Chuck Coulomb, come in. They studied the electrical forces that hold electrons to the nucleus. Atoms attract each other by a complicated dance of nuclei and electrons.

DEMOCRITUS: These electrons, they are also behind electricity?

LEDERMAN: It's one of their main bags.

DEMOCRITUS: So these are gauge bosons, too, like photons and W's and Z's?

LEDERMAN: No, electrons are particles of matter. They belong to the lepton family. Quarks and leptons make up matter. Photons, gluons, W's, Z's, and gravitons make up forces. One of the most intriguing developments today is that the very distinction between force and matter is blurring. It's all particles. A new simplicity.

DEMOCRITUS: I like my system better. My complexity seems simpler than your simplicity. So what are the other five leptons?

LEDERMAN: There are three varieties of neutrinos, plus two leptons called the muon and the tau. But let's not get into that now. The electron is by far the most important lepton in today's global economy.

DEMOCRITUS: So I should worry only about the electron and the six quarks. These explain the birds, the sea, the clouds . . .

LEDERMAN: In truth, almost everything in the universe today is composed of only two of the quarks — the up and the down — and the electron. The neutrino zings around the universe freely and pops out of our radioactive nuclei, but most of the other quarks and leptons must be manufactured in our laboratories.

DEMOCRITUS: Then why do we need them?

LEDERMAN: That's a good question. We believe this: there are twelve basic particles of matter. Six quarks, six leptons. Only a few exist in abundance today. But they were all here on an equal footing during the Big Bang, the birth of the universe.

DEMOCRITUS: And who believes all this, the six quarks and six leptons? A handful of you? A few renegades? All of you?

LEDERMAN: All of us. At least, all the intelligent particle physicists. But this concept is pretty much accepted by all scientists. They trust us on this one.

DEMOCRITUS: So where do we disagree? I said there was an uncuttable atom. But there were many, many of them. And they combined because they had complementary shape characteristics. You say there are only six or twelve such "a-toms." And they do not have shapes, but they combine because they have complementary electrical charges. Your quarks and leptons are also uncuttable. Now, are you sure there are only twelve?

LEDERMAN: Well . . . depends on how you count. There are also six antiquarks and six antileptons and —

DEMOCRITUS: Γρεατ Ζευσ϶σ υνδερπαντσ! [Great Zeus's underpants!]

LEDERMAN: It's not as bad as it sounds. We agree much more than we disagree. But in spite of what you told me, I am still amazed that such a primitive, ignorant heathen could come up with the atom, which we call the quark. What kind of experiments did you do to verify the idea? Here we spend billions of drachmas to test each concept. How did you work so cheaply?

DEMOCRITUS: We did it the old-fashioned way. Not having a Department of Energy or a National Science Foundation, we had to use Pure Reason.

LEDERMAN: So you spun your theories out of whole cloth.

DEMOCRITUS: No, even we ancient Greeks had clues from which we molded our ideas. As I said, we saw that poppy seeds always grow into poppies. The spring always comes after the winter. The sun rises and sets. Empedocles studied water clocks and whirling buckets. One can form conclusions by keeping one's eyes open.

LEDERMAN: "You can observe a lot just by looking," as one of my contemporaries once said.

DEMOCRITUS: Exactly! Who is this sage, so Grecian in his perspective?

LEDERMAN: Yogi Berra.

DEMOCRITUS: One of your greatest philosophers, no doubt.

LEDERMAN: You could say that. But why do you distrust experiment?

DEMOCRITUS: The mind is better than the senses. It contains *trueborn* knowledge. The second kind of knowledge is bastard knowledge, which comes from the senses — sight, hearing, smell, taste, touch. Think about it. The drink that tastes sweet to you may taste sour to me. A woman who appears beautiful to you is nothing to me. An ugly child appears beautiful to its mother. How can we trust such information?

LEDERMAN: Then you do not think we can measure the object world? Our senses simply manufacture sensory information?

DEMOCRITUS: No, our senses do not create knowledge from the void. Objects shed their atoms. That is how we can see them or smell them — like that loaf of bread I told you about. These atoms/images enter through our organs of sense, which are passages to the soul. But the images are distorted as they pass through the air, which is why objects very far off may not be seen at all. The senses give no reliable information about reality. Everything is subjective.

LEDERMAN: To you there is no objective reality?

DEMOCRITUS: Oh, there's an objective reality. But we are not able to perceive it accurately. When you are sick, foods taste different. Water might seem warm to one hand and not the other. It is all a matter of the temporary arrangement of the atoms in our bodies and their reaction to the equally temporary combination in the object being sensed. The truth must be deeper than the senses.

LEDERMAN: The object being measured and the measuring instrument — in this case, the body — interact with each other and change the nature of the object, thus obscuring the measurement.

DEMOCRITUS: An awkward way of thinking about it, but yes. What are you getting at?

LEDERMAN: Well, instead of thinking of this as bastard knowledge, one could see it as a matter of *uncertainty* of measurement, or sensation.

DEMOCRITUS: I can live with that. Or, to quote Heraclitus, "The senses are bad witnesses."

LEDERMAN: Is the mind any better, even though you call it the source of "trueborn" knowledge? The mind, in your world view, is a property of what you call the soul, which in turn is also composed of atoms. Are not these atoms also in constant motion, and interacting with distorted atoms from the exterior? Can one make an absolute separation between sense and thought?

DEMOCRITUS: You make a good point. As I have said in the past, "Poor Mind, it is from us." From the senses. Still, Pure Reason is less misleading than the senses. I remain skeptical of your experiments. I find these huge buildings with all their wires and machines almost laughable.

LEDERMAN: Perhaps they are. But they stand as monuments to the difficulty of trusting what we can see and touch and hear. Your comments about the subjectivity of measurement were, for us, learned slowly in the sixteenth to eighteenth centuries. Little by little we learned to reduce observation and measurement to objective acts like writing numbers in notebooks. We learned to examine a hypothesis, an idea, a process of nature from many angles, in many laboratories by many scientists, until the best approximations to objective reality emerged — by consensus. We made wonderful instruments to help us observe, but we learned to be skeptical about what they revealed until it was repeated in many places by many techniques. Finally, we subjected the conclusions to the test of time. If some young SOB a hundred years later and juicing for a reputation shakes it up, so be it. We rewarded him with praises and prizes. We learned to suppress our envy and fear and to love the bastard.

DEMOCRITUS: But what about authority? Most of what the world learned about my work came from Aristotle. Talk about authority. People were exiled, imprisoned, and buried if they disagreed with old Aristotle. The atom idea barely made it to the Renaissance.

LEDERMAN: It's much better now. Not perfect, but better. Today we can almost define a good scientist by how skeptical he is of the establishment.

DEMOCRITUS: By Zeus, this is good news. What do you pay mature scientists who don't do windows or experiments?

LEDERMAN: Obviously, you're applying for a job as a theorist. I don't hire many of those, though the hours are good. Theorists never schedule meetings on Wednesday because it kills two weekends. Besides, you're not as anti-experiment as you make yourself out to be. Whether you like the idea or not, you did conduct experiments.

DEMOCRITUS: I did?

LEDERMAN: Sure. Your knife. It was a mind experiment, but an experiment nonetheless. By cutting that piece of cheese in your mind over and over again, you reached your theory of the atom.

DEMOCRITUS: Yes, but that was all in the mind. Pure Reason.

LEDERMAN: What if I could show you that knife?

DEMOCRITUS: What are you talking about?

LEDERMAN: What if I could show you a knife that could cut matter forever, until it finally cut off an a-tom.

DEMOCRITUS: You found a knife that can cut off an atom? In *this* town?

LEDERMAN [*nodding*]: We're sitting on the main nerve right now.

DEMOCRITUS: This laboratory, it is your knife?

LEDERMAN: The particle accelerator. Beneath our feet particles are spiraling through a four-mile-around tube and crashing into each other.

DEMOCRITUS: And this is how you cut away at matter to get down to the a-tom?

LEDERMAN: Quarks and leptons, yes.

DEMOCRITUS: I'm impressed. And you're sure there's nothing smaller?

LEDERMAN: Well, yes; absolutely sure, I think, maybe.

DEMOCRITUS: But not positive. Otherwise you would have stopped cutting.

LEDERMAN: "Cutting" teaches us something about the properties of quarks and leptons even if there aren't little people running around inside them.

DEMOCRITUS: There's one thing I forgot to ask. The quarks — they're all pointlike, dimensionless; they have no real size. So, outside of their electrical charges, how do you tell them apart?

LEDERMAN: They have different masses.

DEMOCRITUS: Some are heavy, some are light?

LEDERMAN: Da.

DEMOCRITUS: I find that puzzling.

LEDERMAN: That they have different masses?

DEMOCRITUS: That they weigh anything at all. *My* atoms have no weight. Doesn't it bother you that your quarks have mass? Can you explain it?

LEDERMAN: Yes, it bothers us a lot, and no, we can't explain it. But that's what our experiments indicate. It's even worse with the gauge bosons. The sensible theories say that their masses should be zero, nothing, zilch! But . . .

DEMOCRITUS: Any ignorant Thracian tinker would find himself in the same predicament. You pick up a rock. It feels heavy. You pick up a tuft of wool. It feels light. It follows from living in this world that atoms — quarks, if you will — have different weights. But again, the senses are bad witnesses. Using Pure Reason, I don't see why matter should have any mass at all. Can you explain it? What gives particles their mass?

LEDERMAN: It's a mystery. We're still struggling with this idea. If you stick around the control room until we are into Chapter 8 of this book, we'll clear it all up. We suspect that mass comes from a field.

DEMOCRITUS: A field?

LEDERMAN: Our theoretical physicists call it the Higgs field. It pervades all of space, the apeiron, cluttering up your void, tugging on matter, making it heavy.

DEMOCRITUS: Higgs? Who is Higgs? Why don't you people name something after me — the democriton! By its sound you *know* it interacts with all other particles.

LEDERMAN: Sorry. Theorists always name things after one another.

DEMOCRITUS: What is this field?

LEDERMAN: The field is represented by a particle we call the Higgs boson.

DEMOCRITUS: A particle! I like this idea already. And you have found this Higgs particle in your accelerators?

LEDERMAN: Well, no.

DEMOCRITUS: So you found it where?

LEDERMAN: We haven't found it yet. It exists only in the collective physicist mind. Kind of like Impure Reason.

DEMOCRITUS: Why do you believe in it?

LEDERMAN: Because it has to exist. The quarks, the leptons, the four known forces — none of these make complete sense unless there is a massive field distorting what we see, skewing our experimental results. By deduction, the Higgs is out there.

DEMOCRITUS: Spoken like a Greek. I like this Higgs field. Well, look, I must go. I've heard that the twenty-first century has a special on sandals. Before I continue on to the future, do you have any ideas about when and where I should go to see some greater progress in the search for my atom?

LEDERMAN: Two times, two different places. First, I suggest you come back here to Batavia in 1995. After that, try Waxahachie, Texas, around, say, 2005.

DEMOCRITUS [*snorting*]: Oh, come on. You physicists are all alike. You think everything's going to be cleared up in a couple of years. I visited Lord Kelvin in 1900 and Murray Gell-Mann in 1972, and they both assured me that physics had ended; everything was completely understood. They said to come back in six months and all the kinks would be worked out.

LEDERMAN: I'm not saying that.

DEMOCRITUS: I hope not. I've been following this road for twenty-four hundred years. It's not so easy.

LEDERMAN: I know. I say to come back in '95 and 2005 because I think you'll find some *interesting* events then.

DEMOCRITUS: Such as?

LEDERMAN: There are six quarks, remember? We've found only five of them, the last one here at Fermilab in 1977. We need to find the sixth and final quark — the heaviest quark; we call it the top quark.

DEMOCRITUS: You'll start looking in 1995?

LEDERMAN: We're looking now, as I speak. The whirling particles beneath our feet are being cut apart and examined meticulously in search of this quark. We haven't found it yet. But by 1995 we will have found it . . . or proved it doesn't exist.

DEMOCRITUS: You can do that?

LEDERMAN: Yes, our machine is that powerful, that precise. If we find it, then everything is in order. We will have further solidified the idea that the six quarks and six leptons are your a-toms.

DEMOCRITUS: And if you don't . . .

LEDERMAN: Then everything crumbles. Our theories, our standard model, will be next to worthless. Theorists will be leaping out of second-story windows. They'll be sawing at their wrists with butter knives.

DEMOCRITUS [*laughing*]: Won't that be fun! You're right. I need to come back to Batavia in 1995.

LEDERMAN: It might spell the end of your theory, too, I might add.

DEMOCRITUS: My ideas have survived a long time, young man. If the a-tom isn't a quark or a lepton, it will turn up as something else. Always has. But tell me. Why 2005? And where is this Waxahachie?

LEDERMAN: In Texas, in the desert, where we're building the largest particle accelerator in history. In fact, it will be the largest scientific tool of any kind built since the great pyramids. (I don't know who designed the pyramids, but my ancestors did all the work!) The Superconducting Super Collider, our new machine, should be in full swing by 2005 — give or take a few years, depending on when Congress approves the funding.

DEMOCRITUS: What will your new accelerator find that this one here cannot?

LEDERMAN: The Higgs boson. It will go after the Higgs field. Try to capture the Higgs particle. We hope it will find out for the first time why things are heavy and why the world looks so complicated when you and I know that, deep down, the world is simple.

DEMOCRITUS: Like a Greek temple.

LEDERMAN: Or a shul in the Bronx.

DEMOCRITUS: I must see this new machine. And this particle. The Higgs boson — not a very poetic name.

LEDERMAN: I call it the God Particle.

DEMOCRITUS: Better. Though I prefer a lowercase "g." But tell me: you're an experimenter. What physical evidence have you amassed so far for this Higgs particle?

LEDERMAN: None. Zero. In fact, outside of Pure Reason, the evidence would convince most sensible physicists that the Higgs does not exist.

DEMOCRITUS: Yet you persist.

LEDERMAN: The negative evidence is only preliminary. Besides, we have an expression in this country . . .

DEMOCRITUS: Yes?

LEDERMAN: "It ain't over till it's over."

DEMOCRITUS: Yogi Berra?

LEDERMAN: Yup.

DEMOCRITUS: A genius.

On the northern rim of the Aegean, in the Greek province of Thrace, the town of Abdera sits at the mouth of the river Nestos. As in many other cities in this part of the world, history is written into the very stones of the hills that overlook the supermarkets, parking lots, and cinemas. Some 2,400 years ago, the town was on the busy land route from the motherland of ancient Greece to the important possessions in Ionia, now the western part of Turkey. Abdera was in fact settled by Ionian refugees fleeing from the armies of Cyrus the Great.

Imagine living in Abdera in the fifth century before Christ. In this land of goatherds, natural events weren't necessarily assigned scientific causes. Lightning strikes were thunderbolts hurled from atop Mount Olympus by an angry Zeus. Whether one enjoyed a calm sea or suffered a tidal wave depended on the mercurial moods of Poseidon. Feasts or famines came at the whim of Ceres, the goddess of agriculture, rather than atmospheric conditions. Imagine, then, the focus and integrity of a mind that could ignore the popular beliefs of the age and come up with concepts harmonious with quark and quantum theory. In ancient Greece, as now, progress was an accident of genius — of individuals with vision and creativity. But even for a genius, Democritus was far ahead of his time.

He is probably best known for two of the most scientifically intuitive quotes ever uttered by an ancient: "Nothing exists except atoms and space; everything else is opinion" and "Everything existing in the universe is the fruit of chance and necessity." Of course, we must credit Democritus's heritage — the colossal achievements of his predecessors in Miletus. These men defined the mission: a single order underlies the chaos of our perceptions; furthermore, we are capable of comprehending that order.

It probably helped Democritus that he traveled. "I covered more territory than any man in my time, making the most extensive investigations, and saw more climes and countries and listened to more famous men." He learned astronomy in Egypt and mathematics in Babylonia. He visited Persia. But the stimulation to his atomistic theory came from Greece, as did his predecessors Thales, Empedocles, and perhaps, of course, Leucippus.

And he published! The Alexandrian catalogue listed more than sixty works: physics, cosmology, astronomy, geography, physiology, medicine, sensation, epistemology, mathematics, magnetism, botany, poetic and musical theory, linguistics, agriculture, painting, and other topics. Almost none of his published work survived intact; we know about Democritus primarily from fragments and the testimony of later Greek historians. Like Newton, he also wrote on magic and alchemical discoveries. What kind of man was this?

Historians refer to him as the Laughing Philosopher, moved to mirth by the follies of mankind. He was probably rich; most of the Greek philosophers were. We know he disapproved of sex. Sex is so pleasurable, Democritus said, that it overwhelms one's consciousness. Maybe that was his secret, and perhaps we should ban sex among our theorists so they can think better. (Experimenters don't need to think and would be exempt from the rule.) Democritus valued friendship but thought ill of women. He didn't want children, because educating them would have interfered with his philosophy. He purported to dislike everything violent and passionate.

It is hard to accept this as true. He was no stranger to violence; his atoms were in constant violent motion. And it took passion to believe what Democritus believed. He remained true to his beliefs, though they brought him no fame. Aristotle respected him, but Plato, as mentioned, wanted all of his books burned. In his hometown Democritus was outshone by another philosopher, Protagoras, the most eminent of the Sophists, a school of philosophers who hired themselves out as teachers of rhetoric to wealthy young men. When Protagoras left Abdera and went to Athens, he was received enthusiastically. Democritus, on the other hand, said, "I went to Athens and no one knew me."

Democritus believed in a lot of other things that we didn't cover in our mythical dream conversation, which was pieced together with a smattering of quotes from Democritus's writings and seasoned with some imagination. I took liberties, but not with Democritus's basic beliefs, though I allowed myself the luxury of changing his mind about the value of experiments. I'm confident there's no way he could resist the appeal of seeing his mythical "knife" come alive in the bowels of Fermilab.

Democritus's work on the void was revolutionary. He knew, for instance, that there is no top, bottom, or middle in space. Although this idea was first suggested by Anaximander, it was still quite an accomplishment for a human born on this planet with its geocentric populace. The concept that there is no up or down is still difficult for most people, in spite of TV scenes from space capsules. One of Democritus's further-out beliefs was that there are innumerable worlds of different sizes. These worlds are at irregular distances, more in one direction and fewer in another. Some are flourishing, others declining. Here they come into being. There they die, destroyed by collisions with one another. Some of the worlds have no animal or vegetable life nor any water. Odd stuff, yet this perception can be related to modern cosmological ideas associated with what is called the "inflationary universe," out of which can spring numerous "bubble universes." This from a laughing philosopher who trekked around the Greek empire more than two millennia ago.

As for his famous quote about everything being "the fruit of chance or necessity," we find the same paradox most dramatically in quantum mechanics, one of the great theories of the twentieth century. Individual collisions of atoms, said Democritus, have necessary consequences. There are strict rules. However, which collisions are more frequent, which atoms preponderate in a particular location — these are elements of chance. Carried to its logical conclusion, this notion means that the creation of an almost ideal earth-sun system is a matter of luck. In the modern quantum-theory resolution of this conundrum, certainty and regularity emerge as events that are averages over a distribution of reactions of varying probability. As the number of random processes contributing to the average increases, one can predict with increasing certainty what will happen. Democritus's notion is compatible with our present belief. One cannot say with certainty what fate will befall a given atom, but one can foretell accurately the consequences of the motions of zillions of atoms colliding randomly in space.

Even his distrust of the senses provides remarkable insight. He points out that our sense organs are made of atoms, which collide with the atoms of the object being sensed, thereby constraining our perceptions. As we shall see in Chapter 5, his way of expressing this problem is resonant with another of the great discoveries of this century, the Heisenberg uncertainty principle. The act of measuring affects the particle being measured. Yes, there is some poetry here.

What is Democritus's place in the history of philosophy? Not very high by conventional standards — certainly not high compared with that of virtual contemporaries such as Socrates, Aristotle, and Plato. Some historians treat his atomic theory as a kind of curious footnote to Greek philosophy. Yet there is at least one potent minority opinion. The British philosopher Bertrand Russell said that philosophy went downhill after Democritus and did not recover until the Renaissance. Democritus and his predecessors were "engaged in a disinterested effort to understand the world," wrote Russell. Their attitude was "imaginative and vigorous and filled with the delight of adventure. They were interested in everything — meteors and eclipses, fishes and whirlwinds, religion and morality; with a penetrating intellect they combined the zest of children." They were not superstitious but genuinely scientific, and they were not greatly influenced by the prejudices of their age.

Of course Russell, like Democritus, was a serious mathematician, and these guys stick together. It's only natural that a mathematician would have a bias toward such rigorous thinkers as Democritus, Leucippus, and Empedocles. Russell pointed out that although Aristotle and others reproached the atomists for not accounting for the original motion of the atoms, Leucippus and Democritus were far more scientific than their critics by not bothering to ascribe purpose to the universe. The atomists knew that causation must start from something, and that no cause can be assigned to this original something. Motion was simply a given. The atomists asked mechanistic questions and gave mechanistic answers. When they asked "Why?" they meant: what was the *cause* of an event? When their successors — Plato, Aristotle, and so on — asked "Why?" they were searching for the *purpose* of an event. Unfortunately, this latter course of inquiry, said

Russell, "usually arrives, before long, at a Creator, or at least an Artificer." This Creator must then be left unaccounted for, unless one wishes to posit a super-Creator, and so on. This kind of thinking, said Russell, led science up a blind alley, where it remained trapped for centuries.

Where do we stand today compared to Greece circa 400 B.C.? Today's experiment-driven "standard model" is not all that dissimilar to Democritus's speculative atomic theory. We can make anything in the past or present universe, from chicken soup to neutron stars, with just twelve particles of matter. Our a-toms come in two families: six quarks and six leptons. The six quarks are named the up, the down, the charm, the strange, the top (or truth), and the bottom (or beauty). The leptons include the familiar electron, the electron neutrino, the muon, the muon neutrino, the tau, and the tau neutrino.

But note that we said "past or present" universe. If we're talking about our present environment only, from the South Side of Chicago to the edge of the universe, we can get by nicely with even fewer particles. For quarks, all we really need are the up and the down, which can be used in different combinations to assemble the nucleus of the atom (the kind in the periodic table). Among the leptons, we can't live without the good old electron, which "orbits" the nucleus, and the neutrino, which is essential in many kinds of reactions. But why do we need the muon and the tau particles? Or the charm, the strange, and the heavier quarks? Yes, we can make them in our accelerators or observe them in cosmic ray collisions. But why are they here? More about these "extra" a-toms later.

LOOKING THROUGH THE KALEIDOSCOPE

The fortunes of atomism went through a lot of ups and downs, fits and starts, before we arrived at our standard model. It started with Thales saying all is water (atom count: 1). Empedocles came up with air-earth-fire-water (count: 4). Democritus had an uncomfortable number of shapes but only one concept (count: ?). Then there was a long historical pause, although atoms remained a philosophical concept discussed as such by Lucretius, Newton, Roger Joseph Boscovich, and many others. Finally atoms were reduced to experimental necessity by John Dalton in 1803. Then, firmly in the hands of chemists, the number of atoms increased — 20, 48, and by the early years of this century, 92. Soon nuclear chemists began making new ones