From Leon Lederman, *The God Particle*.

A TALE OF TWO PARTICLES AND THE ULTIMATE T-SHIRT

When I was ten years old, I came down with the measles, and to cheer me up my father bought me a book with big print called *The Story of Relativity,* by Albert Einstein and Leopold Infeld. I'll never forget the beginning of Einstein and Infeld's book. It talked about detective stories, about how every detective story has a mystery, clues, and a detective. The detective tries to solve the mystery by using the clues.

There are essentially two mysteries to be solved in the following story. Both manifest themselves as particles. The first is the long-sought a-tom, the invisible, indivisible particle of matter first postulated by Democritus. The a-tom lies at the heart of the basic questions of particle physics.

We've struggled to solve this first mystery for 2,500 years. It has thousands of clues, each uncovered with painstaking labor. In the first few chapters, we'll see how our predecessors have attempted to put the puzzle together. You'll be surprised to see how many "modern" ideas were embraced in the sixteenth and seventeenth centuries, and even centuries before Christ. By the end, we'll be back to the present and chasing a second, perhaps even greater mystery, one represented by the particle that I believe orchestrates the cosmic symphony. And you will see through the course of the book the natural kinship between a sixteenth-century mathematician dropping weights from a tower in Pisa and a present-day particle physicist freezing his fingers off in a hut on the cold, wind-swept prairie of Illinois as he checks the data flowing in from a half-billion-dollar accelerator buried beneath the frozen ground. Both asked the same questions. What is the basic structure of matter? How does the universe work?

When I was growing up in the Bronx, I used to watch my older brother playing with chemicals for hours. He was a whiz. I'd do all the chores in the house so he'd let me watch his experiments. Today he's in the novelty business. He sells things like whoopee cushions, booster license plates, and T-shirts with catchy sayings. These allow people to sum up their world view in a statement no wider than their chest. Science should have no less lofty a goal. My ambition is to live to see all of physics reduced to a formula so elegant and simple that it will fit easily on the front of a T-shirt.

Significant progress has been made through the centuries in the search for the ultimate T-shirt. Newton, for example, came up with gravity, a force that explains an amazing range of disparate phenomena: the tides, the fall of an apple, the orbits of the planets, and the clustering of galaxies. The Newton T-shirt reads $F = ma$. Later, Michael Faraday and James Clerk Maxwell unraveled the mystery of the electromagnetic spectrum. Electricity, magnetism, sunlight, radio waves, and x-rays, they found, are all manifestations of the same force. Any good campus bookstore will sell you a T-shirt with Maxwell's equations on it.

Today, many particles later, we have the standard model, which reduces all of reality to a dozen or so particles and four forces. The standard model represents all the data that have come out of all the accelerators since the Leaning Tower of Pisa. It organizes particles called quarks and leptons — six of each — into an elegant tabular array. One can diagram the entire standard model on a T-shirt, albeit a busy one. It's a hard-won simplicity, generated by an army of physicists who have traveled the same road. However, the standard-model T-shirt cheats. With its twelve particles and four forces, it is remarkably accurate. But it is also incomplete and, in fact, internally inconsistent. To have room on the T-shirt to make succinct excuses for the inconsistencies would require an Xtra large, and we'd still run out of shirt.

What, or who, is standing in our way, obstructing our search for the perfect T-shirt? This brings us back to our second mystery. Before we can complete the task begun by the ancient Greeks, we must consider the possibility that our quarry is laying false clues to confuse us. Sometimes, like a spy in a John Le Carre novel, the experimenter must set a trap. He must force the culprit to expose himself.

THE MYSTERIOUS MR. HIGGS

Particle physicists are currently setting just such a trap. We're building a tunnel fifty-four miles in circumference that will contain the twin beam tubes of the Superconducting Super Collider, in which we hope to trap our villain.

And what a villain! The biggest of all time! There is, we believe, a wraithlike presence throughout the universe that is keeping us from understanding the true nature of matter. It's as if something, or someone, wants to prevent us from attaining the ultimate knowledge.

This invisible barrier that keeps us from knowing the truth is called the Higgs field. Its icy tentacles reach into every corner of the universe, and its scientific and philosophical implications raise large goose bumps on the skin of a physicist. The Higgs field works its black magic through — what else? — a particle. This particle goes by the name of the Higgs boson. The Higgs boson is a primary reason for building the Super Collider. Only the SSC will have the energy necessary to produce and detect the Higgs boson, or so we believe. This boson is so central to the state of physics today, so crucial to our final understanding of the structure of matter, yet so elusive, that I have given it a nickname: the God Particle. Why God Particle? Two reasons. One, the publisher wouldn't let us call it the Goddamn Particle, though that might be a more appropriate title, given its villainous nature and the expense it is causing. And two, there is a connection, of sorts, to another book, a *much* older one ...

THE TOWER AND THE ACCELERATOR

> And the whole earth was of one language, and of one speech.
>
> And it came to pass, as they journeyed from the east, that they found a plain in the land of Shinar; and they dwelt there. And they said one to another, Go to, let us make brick, and burn them thoroughly. And they had brick for stone, and slime had they for mortar. And they said, Go to, let us build us a city and a tower, whose top *may reach* unto heaven; and let us make us a name, lest we be scattered abroad upon the face of the whole earth.

> And the Lord came down to see the city and the tower, which the children of men builded. And the Lord said, Behold, the people *is* one, and they have all one language; and this they begin to do: and now nothing will be restrained from them, which they have imagined to do. Go to, let us go down, and there confound their language, that they may not understand one another's speech.
>
> So the Lord scattered them abroad from thence upon the face of all the earth: and they left off to build the city. Therefore is the name of it called Babel.
>
> —Genesis 11:1-9

At one time, many millennia ago, long before those words were written, nature spoke but one language. Everywhere matter was the same — beautiful in its elegant, incandescent symmetry. But through the eons, it has been transformed, scattered throughout the universe in many forms, confounding those of us who live on this ordinary planet orbiting a mediocre star.

There have been times in mankind's quest for a rational understanding of the world when progress was rapid, breakthroughs abounded, and scientists were full of optimism. At other times utter confusion reigned. Frequently the most confused periods, times of intellectual crisis and total incomprehension, were themselves harbingers of the illuminating breakthroughs to come.

In the past few decades in particle physics, we have been in a period of such curious intellectual stress that the parable of the Tower of Babel seems appropriate. Particle physicists have been using their giant accelerators to dissect the parts and processes of the universe. The quest has, in recent years, been aided by astronomers and astrophysicists, who figuratively peer into giant telescopes to scan the heavens for residue sparks and ashes of a cataclysmic explosion that they are convinced took place 15 billion years ago, which they call the Big Bang.

Both groups have been progressing toward a simple, coherent, all-encompassing model that will explain everything: the structure of matter and energy, the behavior of forces in environments that range from the earliest moments of the infant universe with its exorbitant temperature and density to the relatively cold and empty world we know today. We were proceeding nicely, perhaps too nicely, when we stumbled upon an oddity, a seemingly adversarial force afoot in the universe. Something that seems to pop out of the all-pervading space in which our planets, stars, and galaxies are embedded. Something we cannot yet detect and which, one might say, has been put there to test and confuse us. Were we getting too close? Is there a nervous Grand Wizard of Oz who sloppily modifies the archaeological record?

The issue is whether physicists will be confounded by this puzzle or whether, in contrast to the unhappy Babylonians, we will continue to build the tower and, as Einstein put it, "know the mind of God."

> And the whole universe was of many languages, and of many speeches.
>
> And it came to pass, as they journeyed from the east, that they found a plain in

the land of Waxahachie, and they dwelt there. And they said to one another, Go to, let us build a Giant Collider, whose collisions may reach back to the beginning of time. And they had superconducting magnets for bending, and protons had they for smashing.

And the Lord came down to see the accelerator, which the children of men builded. And the Lord said, Behold the people are un-confounding my confounding. And the Lord sighed and said. Go to, let us go down, and there give them the God Particle so that they may see how beautiful is the universe I have made.

— The Very New Testament, 11:1

THE FIRST PARTICLE PHYSICIST

He seemed surprised. "You found a knife that can cut off an atom?" he said. "In *this* town?" I nodded. "We're sitting on the main nerve right now," I said.

— With apologies to Hunter S. Thompson

ANYONE CAN DRIVE (or walk or bicycle) into Fermilab, even though it is the most sophisticated scientific laboratory in the world. Most federal facilities are militant about preserving their privacy. But Fermilab is in the business of uncovering secrets, not keeping them. During the radical 1960s the Atomic Energy Commission told Robert R. Wilson, my predecessor and the lab's founding director, to devise a plan for handling student activists should they arrive at the gates of Fermilab. Wilson's plan was simple. He told the AEC he would greet the protesters alone, armed with a single weapon: a physics lecture. This was lethal enough, he assured the commission, to disperse even the bravest rabble-rousers. To this day, lab directors keep a lecture handy in case of emergencies. Let us pray we never have to use it.

Fermilab sits on 7,000 acres of converted corn fields five miles east of Batavia, Illinois, about an hour's drive west of Chicago. At the Pine Street entrance to the grounds stands a giant steel sculpture created by Robert Wilson, who besides being the first director was pretty much responsible for the building of Fermilab, an artistic, architectural, and scientific triumph. The sculpture, entitled *Broken Symmetry,* consists of three arches curving upward, as if to intersect at a point fifty feet above the ground. They don't make it, at least not cleanly. The three arms meet, but in an almost haphazard fashion, as if they had been built by different contractors who weren't talking to each other. The sculpture has an "oops" feel to it — not unlike our Drive east on Pine Street, away from Wilson Hall, and you come to several other important facilities, including the collider detector facility (CDF), designed to make most of our discoveries about matter, and the newly constructed Richard P. Feynman Computer Center, named after the great Cal Tech theorist who died just a few years ago. Keep driving and eventually you come to Eola Road. Take a right and drive straight for a mile or so, and you'll see a 150-year-old farmhouse on the left. That's where I lived as director: 137 Eola Road. That's not an official address. It's just the number I chose to put on the house.

It was Richard Feynman, in fact, who suggested that all physicists put a sign up in their offices or homes to remind them of how much we don't know. The sign would say simply this: 137. One hundred thirty-seven is the inverse of something called the fine-structure constant. This number is related to the probability that an electron will emit or absorb a photon. The fine-structure constant also answers to the name alpha, and it can be arrived at by taking the square of the charge of the electron divided by the speed of light times Planck's constant. What all that verbiage means is that this one number, 137, contains the crux of electromagnetism (the electron), relativity (the velocity of light), and quantum theory (Planck's constant). It would be less unsettling if the relationship between all these important concepts turned out to be one or three or maybe a multiple of pi. But 137?

The most remarkable thing about this remarkable number is that it is dimension-free. The speed of light is about 300,000 kilometers per second. Abraham Lincoln was 6 feet 6 inches tall. Most numbers come with dimensions. But it turns out that when you combine the quantities that make up alpha, all the units cancel! One hundred thirty-seven comes by itself; it shows up naked all over the place. This means that scientists on Mars, or on the fourteenth planet of the star Sirius, using whatever god-awful units they have for charge, speed, and their version of Planck's constant, will also get 137. It is a pure number.

Physicists have agonized over 137 for the past fifty years. Werner Heisenberg once proclaimed that all the quandaries of quantum mechanics would shrivel up when 137 was finally explained. I tell my undergraduate students that if they are ever in trouble in a major city anywhere in the world they should write "137" on a sign and hold it up at a busy street corner. Eventually a physicist will see that they're 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 lonia, 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 Magna Vision 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 bum 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.