From Leon Lederman, *The God Particle* (last reading continued)

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DEMOCRITUS: 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: 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?


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: Γ'000 ypie(()! [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 un-cuttable 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: FpeaT Zeucouv5epmvzo! [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 true-born 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 worldview, 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.