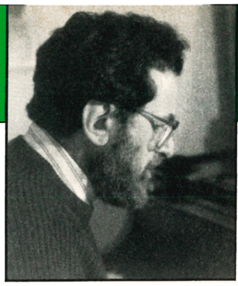

WHATS WRONG WITH THOSE EPOCHS?

N. David Mermin

Ed hai corragio di trattor scherzando un negozio si serio? [And you have the nerve to joke about so serious a business?] —Susanna

My amiable friend Professor Mozart dropped by the other day. Now that his NSF grant has been cut way back, he has more time to think about things, and it's a pleasure to chat with him. Some of his views, though, are more than a little peculiar, as the following conversation clearly reveals.

"I have to admit," Mozart began sadly, "that particle physics over the last 40 or 50 years has been a disappointment. Who would have expected that in half a century we wouldn't learn anything really profound?"

"Nothing profound?!" I exploded. "What about parity nonconservation? What about the breakdown of time-reversal symmetry?"

"To be sure," sighed Mozart, "we've learned that left can be distinguished from right and that time past is different from time future. But most ordinary people knew the difference between left and right all along, and who except the most highly trained physicists—temporarily, it now turns out—ever doubted for a moment that they could tell the future from the past? So establishing that the asymmetry is really there after all is certainly commendable. But about really serious problems we've discovered nothing—nothing whatsoever about the central puzzle."

"And just what might that puzzle be?" I urged, for he seemed in danger of succumbing to an attack of melancholia.

He revived. "All particle physics has taught us about the central mystery is that quantum mechanics still works. Perfectly, as far as anybody can tell. What a letdown!"

"Letdown? It's a triumph!"

"Letdown!" he insisted. "Think of the previous half-century, when we went down from the macroscopic by seven or eight orders of magnitude. What delicious confusion! All the verities of the preceding two centuries, held by physicists and ordinary people alike, simply fell apart—collapsed. We had to start all over again, and we came up with something that worked just beautifully but was so strange that nobody had any idea what it meant except Bohr, and practically nobody could understand *him.* So naturally we kept probing further, getting to smaller and smaller length scales, waiting for the next revolution to shed some light on the meaning of the old one. But what happened? For 65 years, since 1925, we've been probing, at finer and finer levels. That's more than a quarter of the time between 1685 and 1925. And more of us have been working on the problem than the world's entire supply of physicists between Newton and Bohr. As for our *funding* [poor old Mozart still can't keep his mind off funding for very long], well our funding has absolutely dwarfed all the combined funding from Bohr clear back to Archimedes.

"But what have we to show for it? We got from atoms down to the nucleus, and quantum mechanics still worked perfectly. Inside the nucleus it still worked perfectly. Inside the nucleon it's still working perfectly. Here we are today, another seven or eight orders of magnitude down beneath the level of the old revolution, and nothing fundamentally new is in sight—to be sure, some lovely new Lagrangians, but not the slightest trace of a hint of anything better than quantum mechanics. Disappointed? You bet." He picked up my old copy of Bjorken and Drell and thumbed morosely through it.

"But look what else we've learned in the process," I protested. "There's the connection between particle physics and cosmology, that astonishing link between the biggest and smallest of things. We're now studying the very earliest moments after the Big Bang! Even if we haven't managed to shed light on the great issues of principle that preoccupy you, surely we're learning a lot about the raw facts of nature. Why, we can recreate in the laboratory the earliest seconds—the earliest milliseconds—perhaps even the earliest microseconds, back when the whole universe wasn't much bigger than the solar system. Doesn't that make you proud?"

"No," Mozart smiled wanly, "not me. Just calm down, and ask a few old questions. For example, what is time? That's easy: Time is what clocks tell. And what are clocks? Objects you can find in the environment or make out of things you find that behave in a periodic way so you can count cycles. And what was the environment like in that first microsecond or two? Hot, I'll tell you! Spectacularly hot. So hot that the characteristic frequencies of anything worthy of the name "clock" were just unbelievably high. So high that for those clocks a microsecond was just eons and eons of time—probably as long a time for those clocks as the age of the universe is for us today. And that's hardly surprising, since, after all, a microsecond *was* the age of the universe, way back then.

"The fact is," he continued briskly, reverting to his more familiar professorial manner, "that a linear time scale makes no sense in cosomology. It gets us all excited about getting back to the beginning when we're really nowhere near it and never will be able to get anywhere near it. We can only get there in constant seconds, but it's current seconds that matter—the seconds ticked off by the feasible clocks of the current epoch. So all those constant milliseconds back then contained vast ages of current seconds, within which events

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crept in their petty pace from femtosecond to femtosecond. . . ." He subsided back into gloom.

"OK, W. A., so the time scale should be expanded. But why does that matter?"

Mozart gave me the reproachful look he reserves for students who aren't really trying. "If we say we're chasing the behavior of matter down to the earliest milli-, micro- or nanosecond, then we think we're getting somewhere—revealing the great essence of things at the very earliest moments. But I say all we're doing is getting glimpses of epoch 3, epoch 4 and epoch 5, each with its own characteristic phenomenology, each more fleetingly revealed, with literally countless ranks of prior epochs waiting to tease us with still more faintly discernible fragments of their characteristic features. We are, my friend, striving after ever more crude glimpses into the phenomenology of the ever more remote past. Particle physics has become the archaeology of physics. Every time we go up a few orders of magnitude in energy we're able to start constructing the phenomenology of a still earlier epoch. To be sure, that gives us more insight into the epoch that followed it. But beneath the last layer we have learned a little about, there will always be another about which we know nothing.

"Not that the enterprise is without great merit. Somebody has to dig up the pottery shards, note what layers they come from, and try to make intelligent inferences about what they tell us of the era that produced them. Still, it's tame stuff compared with"—here he brightened perceptibly—"the broad and sophisticated views ordinary physics is giving us of the intricate phenomenology of the living present. *De gustibus non est disputandum. . . .*" And a smile of admiration for the wonders of the present epoch brightened his face.

I was glad to see him recover his customary good spirits, but his smugness irritated me. "Hold on, W. A.—when you think about your beloved present epoch you can't avoid the great lesson particle physics has taught us: that everything—absolutely everything—the Sun, Mount Katahdin, you, me, barium titanate, mesoscopic heterostructures—we're all made out of quarks and leptons. That's all there is. Just quarks and leptons, put together in different ways. So what can be more fundamental than learning more about them? The answer to any question you can ask goes back to quarks and leptons."

"That," shot back Mozart, roused from his reverie, "is like wondering what makes Shakespeare so powerful. One day it hits you that everything he ever wrote is made up of words. So you start looking at the plays as bunches of words and make some interesting discoveries. There's only a finite number of these building blocks—less than 50 000. You can order them by frequency, or by the frequency of consecutive pairs, and you discover that Shakespeare has his own characteristic frequencies, which are different from those of other writers, who have their own patterns, and you can even write computer programs that take a text and tell you whether or not it's by Shakespeare. So you think you're getting somewhere, toward a sense of what makes Shakespeare special.

"But then somebody else comes along with another discovery: The words are all made out of letters, and there are only 26 of those—maybe as many as 100 if you want to include punctuation and capitalization. So we've enormously reduced the number of fundamental units out of which Shakespeare's plays are composed. Of course the letter frequencies aren't as useful as the word frequencies in distinguishing Shakespeare from the New York penal code, but they do help in telling him from Dante, and anyway, the words and word–word correlation functions that were so promising a line of attack can all be expressed as higher-order multiletter correlations, so all the information is still there in the letters. Since they're the basic constituents of the words, they have to be more fundamental, more important to study, more exciting a way to approach Shakespeare.

"And then somebody notices something very important about these letters—that they're made up of very similar lines. For example, if you take two parallel vertical lines and connect them with a horizontal line you get an 'H,' but if the line is diagonal, you get an 'N,' so it's all just the arrangement of an even smaller number of little lines. But somebody else discovers ASCII coding and realizes that all of Shakespeare is built up out of just two units: 0 and 1. Then there are the phenomenologists, who say no, that's not the point—it's really two fundamental substances, paper and ink, and the key to Shakespeare lies in the way the ink penetrates the paper."

Mozart sighed deeply. "There are few facts less interesting than the fact that everything is made out of quarks and leptons, even if it does survive the next round of excavations. No, what's important about particle physics is the wonderful archaeology, for its own sake. It's admirable that while most of us are preoccupied with puzzling out and admiring the extraordinary intricacies organized structures of the present epoch present us with, many dedicated souls remain committed to digging out the shards and fragments of the earlier epochs. The time will surely come, at several of the more shallow levels, when they will succeed in assembling their shards into entire beautiful pots." Here he smiled the smile of one who deals in bone china, Wedgewood bowls, Tiffany lampshades and crystal menageries. "And it is my hope," he added benignly as he sailed off toward the elevator, "that someday they will, after all, discover something genuinely profound. Something that teaches us a little more about the serious problem."

"Wait," I shouted as the elevator doors closed. "What about the electroweak unification?" ■

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