MYSTERY, NOT HISTORY, DRIVES PARTICLE PHYSICS

Poor Mozart! I always thought of Mozart as a genius. But the avatar who appeared in David Mermin's Reference Frame column "What's Wrong with Those Epochs?" (November, page 9) seemed to have lost most of his marbles. Not only was he confused about the connection between particle physics and cosmology, but he seemed actually to be hung up on the philosophy of quantum mechanics, a problem in human psychology rather than physical science. If he put drivel about "the central mystery" into his NSF proposal, it's no wonder that his grant was cut.

I am surprised that Mozart, even in his befuddled state, wasn't more excited about quarks. If particle physicists were interested in philosophy rather than science, as Mozart seems to be, we could get pretty exercised over the philosophical implications of quark confinement. Fortunately, we have learned very well, from our experience with relativity and quantum mechanics, that common sense developed at human length scales need not apply at other scales. The fact that we can see quarks inside protons even though the quarks cannot exist on their own has no analog in our everyday experience. Confinement, like relativity and quantum mechanics, is not something that you can understand in your bones the way you understand Newtonian mechanics. You have to get used to it. But that is not what is interesting about quarks. The interesting thing is that the world really works that way! The really exciting thing about unraveling the mysteries of quarks was the discovery of the way the world works at subnuclear distances, not the philosophical pseudoquestions that the discovery might generate.

Much of what Mozart says about "epochs" is correct, but based on a confusion about the nature of the connection between particle physics and cosmology. Indeed, cosmology is a historical science, like archaeology or evolutionary biology, not an experimental science like particle physics.

Of course, the stories of the early universe that cosmologists reconstruct are bound to be incomplete. It is quite natural that cosmologists should want to inform their stories with the most accurate understanding of the way the world works at small distances. However, that is an application of knowledge gained in particle physics, not the business of particle physics itself. We don't do particle physics to understand the early universe any more than poor confused Professor Mozart does condensed matter physics to produce better TV sets.

There is another sense in which what Mozart says is almost correct, and is a good argument in favor of the SSC (perhaps not exactly what the professor intended). While the concepts and insights of particle physics in the last 50 years have been dramatic and new, the types of particles that we study have not changed as much. Indeed, the basic categories of particles were set before quantum mechanics and relativity!

Soon after the discovery of radioactivity, about 100 years ago, the first elementary particles were classified into α rays, β rays and γ rays. These three exemplify the three particle types that particle physicists have studied ever since. The α rays are built of protons and neutrons, which in turn are built of quarks. The β rays are electrons, representatives of the leptons. The γ rays are massless gauge particles, photons, one of the force particles responsible for binding the matter particles into more complicated systems. Until the discovery of the W and Z at CERN, everything else we studied fit into one of these three classes. Indeed the W and Z themselves each have a component that is γ-like. *But they each also have a component that is something completely new!* These new components are the "Goldstone bosons" that are welded to the γ-like parts of the W and Z by the Higgs mechanism to form the massive intermediate vector bosons. In the last 30 years, we have learned enough about the properties of these new components to know that they do not fit into any of the three known classes. Perhaps they are built out of

a new kind of matter particle bound by a new force, stronger than any we have seen. Or perhaps, even more bizarre, they are the partners of a Higgs boson (a hypothetical particle that has *not* been seen and that may or may not exist). Or perhaps (more likely, because Nature is much more imaginative than theoretical physicists) they are something else entirely. We won't know until we look.

This, I believe, is the right way of saying what the SSC is about. It is sometimes said that the SSC is a machine to discover the Higgs boson. But this is nonsense. The Higgs boson may or may not exist. However, the Goldstone bosons certainly do. We have already seen them inside the massive W and Z. We need to get further inside them and find out what kind of stuff they are. We already know that they are some entirely new form of matter, and the interesting questions then are: What else is it good for? What other things are built out of the same or related stuff? This is what the SSC is designed to find out. The SSC will be our first opportunity in nearly 100 years to explore something fundamentally different from anything else we know.

Of course, we could decide that it is not worth doing. It is true that we cannot continue to do particle physics the way it is done today down to much shorter scales. At some point, we must abandon this approach and recognize that some problems will remain forever beyond the reach of our accelerators. But to stop now, when we have identified a new form of matter but not explored its properties, would be a tragic mistake. If our generation of particle physicists fails to make clear just how exciting this is, if we fail to push the SSC to completion and to do good physics with it (or if we lose control of the SSC to government bureaucracy and the military–industrial complex, ending up with a flawed machine like the Hubble mirror), we will leave a blot on the landscape of intellectual history that will disgrace all of basic science. Once Professor Mozart recovers his wits, I am sure that he will not want to encourage such a disaster.

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12/90

Кад Бог хоче неког да уништи прво му памет одузме. (When God wants to destroy somebody, He first takes his mind away.)

—Old Serbian proverb

David Mermin, speaking through Professor Mozart, finds that particle physics in the last 40 to 50 years "has been a disappointment." Having enjoyed Mermin's wit in the past, and having served with him on the panel at the conference in Urbino, Italy, that addressed these fundamental issues, I wondered what happened this time.

It must be that Professor Mozart is suffering from some ailment. Rather than expressing my own opinion (in all such cases, individual tastes vary), let me cite decisions by judges whose tastes we physicists never dispute: the Swedish Academy of Sciences and the Nobel committee. Examining the list of Nobel Prizes in all of physics, beginning with the 1956 award to John Bardeen and his colleagues for the discovery of the transistor and ending with this year's award to Jerome Friedman, Henry Kendall and Richard Taylor, I count 16 prizes in particle physics. This is 50% of the total number of prizes awarded in the last 33 years! To stay on the impartial side, the 1983 award to S. Chandrasekhar and William A. Fowler and the 1982 award to Kenneth Wilson are not among the 16 counted. Neither is the 1978 award to Arno Penzias and Robert Wilson for the discovery of the 3-K cosmic background radiation included in that count, although particle physicists and cosmologists of late treat it as gospel in discourse on the Big Bang.

Surely Professor Mozart has struck a sour note this time—or is it "sour grapes"?

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MERMIN REPLIES: Let me take up Howard Georgi's points in order:

▷ For me one of the fascinating things about quantum mechanics is the clash it opens between the behavior of the physical world and certain ways of thinking about the world that we seem unable completely to avoid. Georgi seems to believe that all moves toward reconciliation should be made on the psychological side. I'm not so sure. But Professor Mozart and I were talking physics, not philosophy. It is a nontrivial experimental fact that quantum mechanics seems to continue to provide the appropriate framework for doing physics even inside the nucleon. I regard this as a triumph. Professor Mozart finds it disappointing. Georgi, despite his professed disdain for philosophizing, seems to take it as true *a priori*.

▷ Professor Mozart loves quarks and the whole phenomenology of colors

and flavors, and can hardly wait for particle physicists to dig down to how the world works at subquark distances. But confinement doesn't befuddle him the way quantum mechanics does. "*Conceptually* it's no stranger than Hooke's law," he says, "except for the absence of a cutoff."

▷ Georgi should not hold Professor Mozart responsible for my own exuberant merging of the goals of cosmology and particle physics. Mozart's point was more subtle: that the possibility of an endless hierarchy of shorter and shorter time scales in the early universe, each with its own characteristic features, suggests the analogous possibility of a hierarchy of shorter and shorter length scales, each with a newer and more "fundamental" particle phenomenology than the one above it. Thus he finds in cosmology some serious warnings about the path particle physicists are pursuing. While it's all a bit speculative for my taste, I can't see the slightest hint of a comparable moral for condensed matter physicists in the behavior of TV sets.

▷ Who said anything about the SSC? Can no opportunity be lost to praise its scientific, intellectual and morally uplifting qualities? As it happens Professor Mozart is a big supporter of the machine. He's filled with curiosity about what will turn up in the next layer and delighted that the public is willing to invest billions in a purely intellectual exercise, with major spinoffs for cosmology. "Certainly it would be tragic to stop digging now," he insists, "comparable to the loss of the Great Library at Alexandria. Whatever the layer at which we finally have to stop, it will be tragic." Nor is he worried about the drain the project might impose on the rest of science. He says his productivity has actually increased since his funding was cut. "Fewer reports to file, fewer graduate students to worry about and more time to follow my nose, wherever it takes me." He is, of course, a theorist, but as for the experimentalists, "A temporary return to string and sealing wax on the kitchen table would refresh them all. Science has become entirely too dependent on high technology. Nor am I among those who would blot the landscape of intellectual history, disgracing all of basic science, for the sake of better TV sets. I'm proud that the American people have decided to put up with low-resolution screens for a few extra years, in their excitement and eagerness to get inside those massive intermediate vector bosons." (I can't agree with Mozart about the Great Library. After all, if we have to wait a century or two the bosons will wait with us, but those plays of Euripides and Sophocles are gone forever.)

Unlike Georgi, who suggests that Professor Mozart may have "lost most of his marbles," Drasko Jovanovic merely thinks him diseased. I am puzzled by the violence of both responses. Mozart seems to think that the last word has not yet been said on the meaning of the quantum theory—that experiment may still have something more to teach us; that we will find endless hierarchies of new structure as we probe to shorter and shorter length scales; and that naive reductionism is too innocent a basis for a deep understanding of the physical world. I can understand disagreeing with any or all of these opinions, but is holding them evidence of dementia? As for the argument Jovanovic offers in support of his diagnosis, I can only say that while I myself sometimes orchestrate a case for a prize for good physics, I am entirely unimpressed by the view that, conversely, prizes or even Prizes provide a definitive measure of scientific merit. (See my Reference Frame column of January 1989, page 9.)

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1/91

Reflections on Broken Symmetry

Philip W. Anderson (May 1990, page 117) states that ferromagnetism is not a case of broken symmetry, but that antiferromagnetism is, because in the latter "the" ground state is not an eigenstate of the symmetry. I must disagree. If there is a unique ground state, it must of course respect the symmetry. The real question is whether the eigenstate of the order parameter belongs to a representation of the symmetry group. In ferromagnetism one may assume the order parameter to be the magnetization, including both magnitude and direction, in which case it does not respect the spin rotation symmetry. In the macroscopic limit an alternative is to choose the magnitude of the magnetization and the direction in which the component is maximum. This does define a representation of the group, and the fluctuations in direction are negligible in the macroscopic limit.

In the antiferromagnet the same is true as regards the spin rotation group. There is, however, a further symmetry here: the displacement that interchanges the even and odd sites. The antiferromagnetic order clearly breaks that symmetry. The