

OPINION

'Particle Physics and Our Everyday World': A Reply

Robert N. Cahn

In the July issue of *PHYSICS TODAY* (page 58), Pablo Jensen took issue with some statements I made in a pedagogical article.¹ In that article, I explained how the empirical parameters of the Standard Model of particle physics shape the most familiar aspects of our physical surroundings. We can take these parameters to be the masses of the quarks and charged leptons; the strength of three forces; four numbers that describe the weak transformations of one quark type into another; the mass of the W boson; and the mass of the Higgs boson.

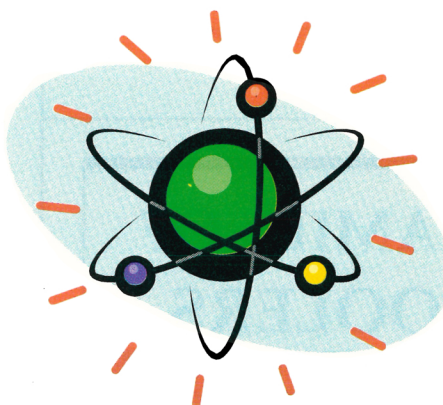
Given these parameters, the Standard Model (which subsumes the Maxwell and Schrödinger equations) determines all the fundamental processes of electroweak and strong interactions. Changes in the basic parameters would produce worlds quite different from our own. The Standard Model provides no guidance as to the values of the fundamental parameters, although few physicists believe they are truly arbitrary. Rather, it seems likely that there is some simpler and more complete scheme with fewer free parameters from which our current theory follows.

Until we can explain why the parameters take the values they do, we cannot truly say we understand why the world came out as it did. Were the electron as massive as its sister particle, the muon, the universe would be filled with nothing but neutrons and neutrinos. Were the W boson's mass twice as great, the Sun's radius would be 33% smaller and its surface 22% hotter. Even more dramatic changes can be imagined. Supersymmetry asserts that for every fundamental fermion there is a yet-to-be-seen partner spin-zero boson. If this is true, these partners are very massive. Had they been lighter than the fermions, this would be a very different place, with all matter fused into a single all-encompassing macromolecule.

In contemporary physics research outside of particle physics, the constituents of matter and the forces

among them are givens. Within that framework, quantum mechanics and electrodynamic interactions are exploited effectively to explain diverse substances and phenomena, both mundane and extraordinary. If we wish to understand the constituents and the forces themselves, then it is to particle physics that we must turn.

The stuff of quotidian life is made just of electrons and the lightest quarks. However, we cannot understand these particles by themselves, because they are intimately connected to others accessible only in high-energy collisions. Our task would be hopeless if it were true that "breaking matter



with higher and higher energies will give you more and more 'fundamental' particles," as Pablo Jensen asserted in his recent "Opinion" column. In fact, just the opposite is true. Instead of the random leptons and myriad resonances of the 1960s, today there are just twelve fundamental particles—three repetitions of four basic fermions. Moreover, we now see that there are fewer forces, not more, than we thought 30 years ago.

This simplification is a result of theoretical and experimental advances, including the discovery of neutral weak currents, the c, b and t quarks, the τ lepton and the W and Z bosons. Experiments at accelerators around the world uncovered the simple pattern of the quarks and leptons and elucidated the strong and electroweak interactions between them. Even more important than the questions that have been answered are the ques-

tions we can now ask. To learn how the masses of the particles arise and whether there are supersymmetric partners, we need to explore higher energies. Clues to these questions are known to lie at around 1 TeV, the scale to be explored by CERN's Large Hadron Collider (LHC).

In his "Opinion" piece, Jensen chastises the particle physics community for its "reductionist vision," argues for "a vision of science as an array of autonomous layers" and claims that "particle physics is practically irrelevant to understanding our everyday world."

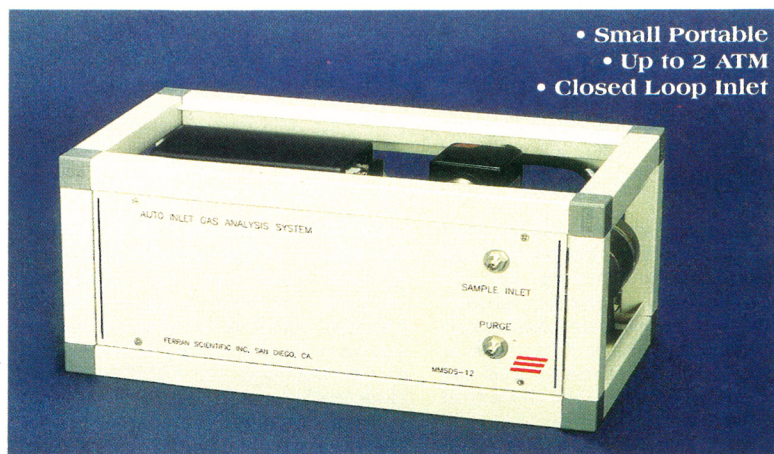
In response to the first criticism, I quote Philip W. Anderson: "The reductionist hypothesis may still be a topic for controversy among philosophers, but among the great majority of active scientists I think it is accepted without question."² We physicists do not argue that fundamental laws will lead directly to an understanding of every macroscopic phenomenon. When large numbers of particles are combined, phenomena arise that cannot be anticipated directly from the behavior of a few isolated particles. This collective behavior is not the result of new forces. There is no superconductivity force, for example, and whatever explanation triumphs for high-temperature superconductors will rely on the known forces and on quantum mechanics. Constructs that embody the essential physical features of complex systems are indispensable, but their success is not a reason for abandoning the search for basic physical laws.

Nature is not neatly partitioned into autonomous layers, as Jensen suggests; on the contrary, the macroscopic makes manifest the microscopic. Niels Bohr was driven to invent quantum mechanics because the stability of matter required it. The gross properties of the materials around us, their color, conductivity and strength, reflect the details of their quantum mechanical states. Likewise, the structure of atoms reflects divisions in the subatomic world. Hadrons, which enjoy strong interactions, are bound tightly at the center of the nucleus, while electrons, which as leptons lack strong interac-

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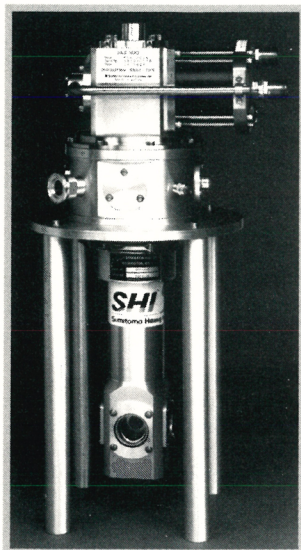
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tions to constrict them, roam broadly. When we pull off a sweater, we feel macroscopic static electric fields because photons are massless, yet we never see the likewise massless gluons because they are confined within the nucleus by their self-interactions. Only by willfully closing our eyes can we miss the connection between the fundamental interactions and their manifestations that surround us.

Issues for particle physics

The issues central to particle physics today—light, matter and forces—confront our senses directly and have been concerns of physicists since the time of Newton. Thirty years ago, questions such as, Why is there light? Why is the electron's mass so small? were outside of science. Thanks to the Standard Model, we can now address them both theoretically and experimentally.

We now understand light as part of the electroweak force. What we don't understand is why the photon is massless while its partners, the W and Z bosons, are very massive. We don't understand what determines the masses of the matter particles, the quarks and leptons. We have learned enough, however, to design experiments that should give us essential clues. At Fermilab and CERN, physicists are now looking for new particles, vestiges of the mechanism that gives mass to most particles, but leaves the photon massless. The LHC is designed to address these questions definitively. That there is matter at all requires, as Andrei Sakharov showed, violation of the CP symmetry, which connects particles to antiparticles. Experiments will begin soon at several laboratories around the world to study CP violation in B mesons.

We particle physicists share with all physicists the goal of explaining the world. We differ only by asking ever more basic questions. Like young children who relentlessly insist, Why?, particle physicists ask, Why is there light? Why are electrons light and protons heavy? Why are there electrons or protons, anyway? "Just because" and "Who cares" will not satisfy the curious child, nor should they satisfy us.

References

1. R. N. Cahn, Rev. Mod. Phys. **68**, 951 (1996).
2. P. W. Anderson, New Scientist, **51**, 510 (1971).

Editor's note: See "Letters," page 15, for other comments on Pablo Jensen's essay. ■