

not higher-order coherence. In any case, by the time the beam would be collimated enough to search for coherence, its intensity would be effectively zero.

Anthony Siegman is not concerned with semantics but with physics. For him the distinguishing feature of a laser is its role as an amplifier, rather than the coherence properties that I emphasized. However, it seems to me that even from this point of view the term "atom laser" is apt. As I described, the field in an atom laser—the atom field of the system's ground state—grows by stimulated scattering, in close analogy with stimulated emission in a laser. From this point of view, the atom laser demonstrates amplified spontaneous scattering (I forgo the acronym), in close analogy to the ASE laser he cites.

Because of the differing views on what constitutes a laser, I understand why "atom laser" might be regarded as a misnomer. Nevertheless, it still seems to me that it is a pretty good nomer.

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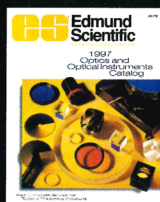
The Constructs of Physics and the Role of Math—Revisited

I never had a formal education in philosophy, nor do I think my epistemological insights gained from lifelong research are particularly deep; nevertheless, I think that there is something very wrong with Lorenzo de la Torre's letter (PHYSICS TODAY, September 1997, page 15).

I believe the following quotes from his letter summarize his views: "[P]hysical reality is, to some extent, a *construct* of our own; . . . we *construct* physical reality so that it complies with mathematics. . . . [M]athematics is inherent in the *construction* of . . . physical reality" (emphases added).

Although I am certainly not a rabid materialist, I must take issue with his ultraidealistic views. I fully agree with him when he says that "[t]he use of quantities in theoretical explanations and predictions, and in the analysis of experimental data, is innately connected to mathematics. Physics characteristically looks for natural laws that have a mathematical structure." Sure—but we do not *construct* reality, either with or without mathematics! At the very best, we construct something like "images

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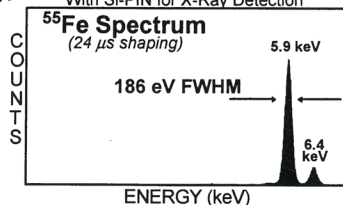
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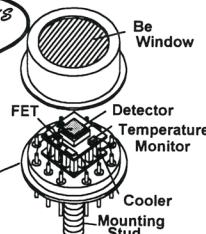
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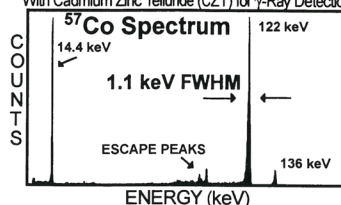


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of reality." Viewing the world essentially from the angle of what may be called contextual realism, I believe that physical reality exists objectively whether we are aware of it or not. However, this reality is not directly accessible to us: It must be recognized, grasped, contemplated, correlated and exploited through the medium of some structure, which indeed, as Einstein put it (and as de la Torre quotes him), "cannot be extracted from experience but must be freely invented." Experience (that is, observation and experiments) gives us "signatures" (or indicators) of bits of objective physical reality, but to assimilate them, we need to interpret and integrate them into an invented structure that then puts these bits into a specific context. And we formulate the contextual structure in terms of mathematics. This is not surprising since, by modern definition, mathematics is the science of structures. Therein lies the "sovereign role" (as Eugene Wigner used to say) of mathematics, rather than in that it enables us to make calculations.

It may be thought that de la Torre and I differ only in semantics, and when he speaks of "our construct[ing] physical reality," he simply means creating the mathematical structures that interpret reality by putting our experiences into a context. However, de la Torre cannot be interpreted accurately in this manner, as evidenced by three of his examples.

First, following Carl Adler's "analysis" of the epochal Reines-Cowan experiment, de la Torre says that "the neutrino can exist only in a certain context." In truth, the existence of the neutrino was first suggested by beta-decay experiments and the need to reconcile their results with the experimentally established and theoretically well-understood law of energy-momentum conservation. Motivated by the frame of this context, Reines and Cowan manifestly verified the real existence of an object that has the properties foretold in a context. By now, this context has changed in several ways. For example, instead of the four-fermion interaction, we have the electroweak interaction framework, and we also have recognized, by experiments, additional properties of the neutrino, discovered two "other" neutrinos and so forth. However, independent of all these contexts and mathematical structures, the thing known as a neutrino still exists, and it will always exist, "out there." True, we may have to conceptualize it differently, but it surely exists, in Adler's words (as quoted by de la Torre) "apart from the theory and



"QUARKS. NEUTRINOS. MESONS. ALL THOSE DAMN PARTICLES YOU CAN'T SEE. THAT'S WHAT DROVE ME TO DRINK. BUT NOW I CAN SEE THEM."

experiments that define it."

Second, de la Torre says: "if the theory of special relativity were to turn out to be false . . . the existence of our elementary particles would be challenged." No: If special relativity were to be contradicted or modified by experience or by a (superior) "freely invented" frame, the "particles" (whatever they are) would still exist objectively, even though we would have to conceptualize and systematize them within another context and with the help of another mathematical structure.

Third, de la Torre tells us: "As evident in the example of the top quark, mathematics plays an inherent role in this process of *construction of physical reality*" (emphasis added). True, the experimental search for the top quark was motivated by the mathematical and conceptual framework of the Standard Model (even though we do not have a firm basis for why three flavor-doublets of quarks should exist—aesthetic considerations come in here as well!). However, once this object of nature, satisfying the contextually expected objective properties, was "seen" by its signature, we could speak of its realistic existence, independently of the Standard Model. Actually, its discovery gave us the surprise of an unexpectedly high mass—and certainly many more of its properties and its relations to other quarks will come forward in time. As an ob-

ject of nature, it will always be "realistic." It is not our creation.

Surely we do not really know what elementary particles are. We may conceptualize, describe, interpret, systematize and correlate them in several contextual structures: corpuscular theories, abstract group theoretical arguments, quantum theory of fields or even string theory. The list will surely grow in the future, but there those particles are and always have been, bits and pieces of an objective, not-by-us-constructed universe.

There are many things betwixt Heaven and Earth, but it is not we who create them.

PAUL ROMAN
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Although Lorenzo de la Torre has supplied a clear and succinct statement of why physical theories are so intimately entwined with mathematics, one of his statements paints an inaccurate picture of what physics does: "It is clear that we systematically construct physical reality with certain preconceived mathematical structures; we adjust physical reality so that it agrees with mathematics."

A more accurate statement would be: "It is clear that we create mental constructs about physical reality—such as particles, forces, fields, parameters, models and theories—that make use of existing mathematical structures: we interpret physical reality with the aid of these structures in a manner to explain existing observations and make predictions of new observations."

The constructs of physics are physically real only in that they lead to explanations and predictions of observations of physical reality. I believe this distinction is important for three reasons: (1) physics did not create physical reality, (2) it is the ability of physics (and other sciences) to quantitatively explain and predict that gives them their unique and valuable qualities and (3) science is under attack as being no more valid, and thus no

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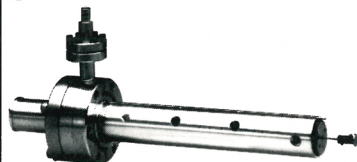
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more useful, than any other belief system. In a society increasingly dependent on science and with science being increasingly dependent on society, it is important that science be seen as concerned with the reality experienced by everyone, not of the reality of its own creation.

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Lorenzo de la Torre's letter contains a mixture of cogent observations and misleading conclusions. For example, although it is true that many observational facts are theory laden (as many commentators on science put it), this does not necessarily imply that the facts are therefore context dependent. Leaving aside the metaphysical notion of the existence of particles, what gives them the needed stability for us to have confidence in them is their coherence with the interpretation of many other observations. This is the relevant context. In some areas, this context is relatively limited and the theory-laden facts may temporarily be subject to some doubt; in others, the context is so large that lack of confidence would be quixotic. Neutrinos surely are by now in the second category.

To conclude from the fact that the top quark is a mathematical necessity in the Standard Model that "mathematics is essential for the very existence of many elementary particles" is to put the cart before the horse. The theory predicts or implies their existence; that does not mean that after being found, they would not exist without the theory.

De la Torre thinks that "we find that reality is mathematical in nature" because "mathematics plays an inherent role in this process of construction of physical reality." I don't know what "reality is mathematical in nature" means, but the fundamental reason why we use mathematics in physics is that, as I have elaborated elsewhere,¹ it is the most powerful and most economical instrument of logical thought, and we need it as a tool for understanding reality.

Reference

1. R. G. Newton, *The Truth of Science: Physical Theories and Reality*, Harvard U. P., Cambridge, Mass. (1997).

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DE LA TORRE REPLIES: One can say that physical reality exists objectively whether or not one is aware of

it, and that physical objects such as neutrinos exist completely independent of the contexts in which they have been predicted and confirmed. Let us call that level of reality "World One."

One can also say that sensory impressions, concepts, connections among concepts, experimental arrangements and rules for data analysis are kinds of knowledge and that they form a large structure that may be called "World Two." Accordingly, World Two would be a representation of World One (and, for some people, perhaps even a faithful mapping of World One). There is nothing wrong with World One, except that we know little—or probably nothing—about it because it is not directly accessible to us. The following question is crucial: Do words such as "objectivity," "reality" and "truth" refer to World One or to World Two? Centuries of discussion show that this question has not been resolved.

Physics does not provide a clear picture of what an electron is, but does provide a good description of its behavior under different circumstances. In this case, we see physics dealing mainly with the interactions among things. Here, the big question is not the reality of things, but the reality of processes. And it is here, in the conception, observation and analysis of processes, that our creativity plays a role. I do not claim that processes are entirely a construction of the human mind; but I can see elements of artificiality in the physical process that took place in the Reines-Cowan experiment of 1956, and in the conclusion drawn from it: the discovery of the neutrino.

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Physicist Honored for Acting Bravely—and without Uncertainty

Silvan Schweber's review of Abraham Pais's autobiography in your October 1997 issue (page 99) tells of Hans Kramers writing to Werner Heisenberg for help in saving Pais, who had been arrested by the SS. Heisenberg replied that he "could do nothing."

Although we must come to terms with individuals whose work we admire but whose personal life is not above reproach, our disillusion is redressed by knowing of individuals who may not (yet) be Nobelists but who have behaved admirably. Like