Because QFT is so neglected by the public (and by many physicists), I am writing a book that presents it without equations. A draft copy of the work, *The Theory That Escaped Einstein*, can be found through an internet search. Feedback is appreciated.

For those who can't kick the reification habit, QFT is the way to go. It is the only theory that offers a consistent and visualizable picture of reality. Reifiers of the world, unite! You have nothing to lose but your abstractions.

References

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I am curious to hear David Mermin's view, in light of his May 2009 Reference Frame, of Galileo's condemnation by the church.

That episode is still considered a scandal by most scientists. For example, several physicists cited the Galileo affair as their reason for opposing the visit of Pope Benedict XVI to the University of Rome I ("La Sapienza") last year.

Could we perhaps say that Mermin would agree with those who refuse to recognize any objective truth in physical theories yet support them as useful descriptions of successions of events, thus condemning Galileo's quest for ontologically realistic theories?

Is the proposition that Earth travels around the Sun ultimately a mere calculational device?

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David Mermin points out a "bad habit" that afflicts most humans: mistaking a computational idealization for the real world. That would probably not be intellectually fatal. What can lead to brain damage is to take the real world to be an approximation of the ideal, rather than doing the reverse.

We talk about geometric shapes such as lines, circles, and spheres. Each of these words conjures up a picture of a perfect line, circle, or sphere. We know that no real line is perfectly straight and no circle can be made without imperfections, however minute. Yet our mental image is of the perfect geometric shape.

So it is easier in most cases for the mind to grasp the ideal rather than the real. Perhaps Nature is punishing us for our bad habit, forcing us to keep burning up CPU time without getting to the end of π. Not falling prey to the bad habit Mermin so beautifully discusses would clear up a lot of smoky haze in the intellectual environment.

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David Mermin criticizes the "reification" of magnetic fields, but he allows that spark chamber trajectories and atomic spectra are real, so why not also accept magnetic fields, ionic lattices, the cosmic microwave background, and so on? And is reification such a bad habit? Intuitive flashes of insight come as much from immersing yourself in the reality of the physics as from holding your nose and manipulating formal symbols. Often, reification leads us in the right direction: I assume Mermin has no plans to revive Mach's crusade against the reality of the atom.

I sympathize with Mermin's desire to distinguish between mathematical abstractions like quantum field operators and solid realities like metals, but by any reasonable standard, magnetic fields are just as real as equally invisible variations in air pressure. Mermin worries that quantum mechanics describes fields—and atoms and everything else—in weird abstract terms, but allowing the weirdness of quantum mechanics to undermine the normal concept of what is real seems like a case of taking a successful theory too seriously, which is just what he was warning us not to do.

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Does David Mermin believe atoms are real?

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Life certainly would have been easier for Albert Michelson and Edward Morley if only they hadn't reified the ether! Then they'd have been free to do less difficult things than look for evidence of it. After all, it was a perfectly useful abstraction for physicists who thought all waves require a medium.

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David Mermin seems to advocate the view of theoretical paradoxes and controversies of quantum mechanics and field theory as problems of "tools" of a linguistic or otherwise technical nature. His advice is not to "make life harder than it needs to be." First, philosophical reduction of a fundamental science to a human tool goes against the main quest of science – the quest for objective truth about the universe. Second, the suggested advice seems more conducive to peace of mind than to scientific inquiry. Paradoxes and contradictions have always been a rich source of inspiration and contemplation for those who are seeking new knowledge.

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"I hope you will agree," David Mermin writes, "that *you* are not a continuous field of operators on an infinite-dimensional Hilbert space. Nor, for that matter, is the page you are reading or the chair you are sitting in." His comment is a nice example of the logical fallacy known as "appeal to belief": Most people believe X is true, so X is true. That many people believe they are not operators in Hilbert spaces, believe they do have free will, or do or don't believe in global warming makes no difference as to whether a statement is true or false. I have no basis on which to decide what I "really" am. And though I personally think any such argument is a waste of time because it can never be decided anyway, and though I am sympathetic to the opinion Mermin expresses, his article dismisses the relevance of both quantum foundations and the philosophy of science out of hand in a rather polemic and not very insightful way.

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David Mermin cautions against taking our "most successful abstractions to be real properties of our world." I think he has set up a straw man. To me, the tenable realist position is not that our concepts are real but rather that they have a correspondence to reality: There can be many such correspondences, each with its utility, none capturing reality—whatever that is.

I am not surprised he uses that argument to bolster the position "that quantum states are calculational devices." In the vein of the disagreement about reality he cites, between Bishop Berkeley and Samuel Johnson, I recall a similar disagreement, between Mermin and John Bell, concerning the foundations of quantum theory. It took place at a meeting in Erice, Italy, in August 1989. Bell had finished his now famous talk "Against 'Measurement,' " in which he argued that there is something wrong with quantum theory, that its rules of application are ill-defined.[1] He introduced the acronym FAPP, meaning that quantum theory is good "for all practical purposes" but insufficient for a truly fundamental theory. In the question-and-answer session, Mermin gave an argument not unlike the one in his Reference Frame. When he was done, Bell replied, "FAPPtrap," and that was that.

Mermin says that if one takes his view, it "can diminish the motivation for theoretical or experimental searches for a 'mechanism' underlying . . . the 'collapse of the wavefunction'—searches that make life harder than it needs to be." But why would one want to diminish such motivation? Might not the deficiencies of quantum theory elucidated by Bell be a clue to some deeper theory? And is that not good for physics? Certainly, in this generation, in which we did not predict the acceleration of the universe nor know the nature of dark energy or dark matter, we should have the humility to think that perhaps we do not yet have the "final" quantum theory.

For example, in standard quantum theory, how or why an event occurs is a complete mystery. Nature determines an outcome, but we are told it is impossible for us to understand that in terms of anything deeper. Things happen for no reason at all. Why should we follow Mermin's advice and not try to do better?

In my own work and that of GianCarlo Ghirardi, Alberto Rimini, and Tullio Weber, we have developed what is called a dynamical theory of wavefunction collapse (continuous spontaneous localization, or CSL).[2] To Schrödinger's equation, a term is added that describes the interaction of matter with a randomly fluctuating field, so that a state vector in a superposition of macroscopically different states rapidly evolves to one of them. The final state describes the world as we see it. Therefore, the state vector can be said to correspond to reality and not be merely a computational device. Bell regarded CSL as an example of a well-defined theory, which overcomes his objections to standard quantum theory. Moreover, it provides a mechanism, a description, for the occurrence of events. And it makes some predictions that differ from those of standard quantum theory, so it is experimentally testable. Experiments so far have shown that the coupling of random field to matter must be mass proportional, but otherwise they have neither confirmed CSL nor denied it. This is a good thing, and that such attempts should not be discouraged, as Mermin's article does, was underlined by Richard Feynman, who said in 1964,

> We have to find a new view of the world that has to agree with everything that is known, but disagree in its predictions somewhere, otherwise it is not interesting. And in that disagreement it must agree with nature. If you can find any other view of the world which agrees over the entire range where things have

already been observed, but disagrees somewhere else, you have made a great discovery. It is very nearly impossible, but not quite, to find any theory which agrees with experiments over the entire range in which all theories have been checked, and yet gives different consequences in some other range, even a theory whose different consequences do not turn out to agree with nature.[3]

References

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Mermin replies: Rather than attempting a general definition of "real" and "abstract," I illustrated with examples what it means to reify an abstraction. Michael Nauenberg and Derek Walton insist on a definition, though Walton agrees with me that it's not easy to provide one. In their own definitions, Nauenberg assigns reality to phenomena or events that can be recorded by a device, and Walton says reality is that which can be observed. These can be compared with what I came up with toward the end of my essay, though I offered it as a sufficient condition for reality rather than a definition: "What impinges directly upon us is real." My warning against extending reality to the abstractions that help us impose coherence on our perceptions works almost as well if you replace "our perceptions" by "what the device records" or "what we observe."

In quoting my phrase that "spacetime is an abstract four-dimensional mathematical continuum of points that approximately represent phenomena," Nauenberg drops the rest of my sentence: "whose spatial and temporal extension we find it useful or necessary to ignore." Representing phenomena (or, if you prefer, the location of phenomena) by abstract geometric points is invariably an idealization of a state of affairs that in reality is not sharply defined. The fact that crude (on some scale) spatial or temporal distances can be recorded irreversibly by macroscopic instruments does not confer reality on the continuum of ideal points we use to represent such data.

Nauenberg remarks that interpretational problems in quantum physics usually come from attempts to impose views of reality learned from classical physics on the microscopic world. I would have said "sometimes." As Mark Alford critically notes, I also believe that even in classical contexts we should look more skeptically at some of our classical ideas of what is real.

I mentioned Werner Heisenberg's views on the acquisition of knowledge only in the context of whether wavefunction collapse is a real physical process, produced, for example, by Philip Pearle's randomly fluctuating field. Heisenberg believed, on the contrary, that "collapse" was merely our updating of information. Although Nauenberg dismisses Heisenberg's views as irrelevant to the question of what is real, he seems to agree with Heisenberg in declaring that wavefunction collapse is no more mysterious than the change in a probability distribution after an outcome is recorded.

Nauenberg's colleagues, Fred Kuttner and Bruce Rosenblum, come at me from quite a different direction, reading me as deploring books that honestly and interestingly present the strangeness of quantum physics. But I've even tried to write such a book myself. What I do deplore is making quantum mechanics sound more peculiar than it already is. Physicists can be as guilty of this as mystics.

In particular, separating the strangeness of the uninterpreted data from the strangeness of the formalism that accounts for those data is a subtle business. One of the things the pilot-wave interpretation of quantum mechanics does perfectly well is to provide a straightforwardly unweird explanation of two-slit particle diffraction: A wave goes through both slits and directs a real particle to the screen on the other side, guiding it through one slit or the other. So I do not agree with Kuttner and Rosenblum that the two-slit data, in and of themselves, boggle the mind, independent of one's perspective on the quantum theory. And I would say that what is usually called "the measurement problem"—the issue that Pearle addresses—is impossible to formulate without invoking the orthodox quantum formalism.

It's a pleasure to become reacquainted with my old friend Rodney Brooks after half a century. I'm glad he agrees that the field operators are mathematical tools, and I apologize for misconstruing his 50-year-old views. But I do think appealing to quantum field theory to solve the paradoxes of special relativity is using a sledgehammer to crack a walnut. Abandoning the reification of time does the job all by itself.

Leonardo Colletti wonders what I think about Galileo's condemnation by the church. I'm with Galileo. It was the church that was (and still is) guilty of reifying abstractions. I do not "agree with those who refuse to recognize any objective truth in physical theories," but I also think that Colletti's "mere calculational device" undervalues the beauty and power of the best abstractions physicists have come up with. A coordinate system fixed in the rotating Earth, with real—to use a dangerous term—centrifugal and Coriolis forces, is just fine for most terrestrial purposes. It's pretty poor for describing the solar system, and a disaster for cosmology.

What's important is not to succumb to the belief that the correct coordinate system is built into the nature of things, as the church did for one coordinate system, and as Colletti seems to favor for another. We should choose the one that best suits our purpose. In an only slightly different context, Galileo understood this very well. That's why we talk to this day of Galilean transformations.

Experimentalists have been much more sympathetic than theorists to my views on reification. They seem to be less enchanted by their abstractions. I'm glad Amin Dharamsi understood what I was trying to say, and would only add to his examples the simplest of all geometric abstractions—the single point—which plays a central role in my remarks on the reification of spacetime.

Alford finds spark chamber trajectories analogous to magnetic fields. I would have said they were analogous to Faraday's iron filings. He goes on to warn against letting quantum mechanics undermine our normal classical sense of reality. The doubts I raised about the reality of classical electromagnetic fields did come entirely from quantum electrodynamics. But my qualms about the reification of the spacetime continuum (which, to my surprise, nobody but Nauenberg objected to) are based entirely on classical physics, untainted by quantum weirdness.