not part of Bohr's terminology, we can imagine that he might have responded as indicated to the question posed. We see the statement in relation to his basic view that the algorithm of quantum mechanics is a purely symbolic formalism accounting for observations that are obtained under specified conditions. That view is illustrated by his advocacy that the word "phenomenon" be used exclusively to refer to "an observation obtained under specified circumstances, including an account of the whole experimental arrangement. In such a terminology, the observational problem is free of any special intricacy, since, in actual experiments, all observations are expressed by unambiguous statements referring, for instance, to the registration of the point at which an electron arrives at a photographic plate."[2]

Interpreted in this manner, the dismissal of a quantum world leaves the particle as an object capable of directly producing the basic event of observation, such as the registration of an electron arriving at a photographic plate or a click produced in a counter. As is evident in the conflicting reactions that Mermin reports, the issue of which world these objects belong to remains controversial.

Mermin asks, What's wrong with this quantum world? Our answer is that the rejection of it in the form described does not go far enough. As we have recently argued,[3] the perceived need to explain the click as being caused by a particle is a remnant from classical imagery, which has obscured the full implications of fortuitousness and thereby the principle underlying quantum mechanics. Thus all experimental evidence is consistent with a complete break with causality in that the click comes without any cause, as a genuinely fortuitous event. The event is recognized as a macroscopic discontinuity in the counter. Thus genuine fortuitousness unavoidably eliminates the particles. Although fortuitousness has been a central innovation of quantum physics, a complete break with causality was beyond the horizon of the pioneers of quantum mechanics. Indeed, if there were no particles producing the clicks, what would the theory be all about?

Perhaps surprisingly, the very notion of genuine fortuitousness is powerful in its implications. With particles excluded, only geometry is left on the stage, and the symmetry of spacetime itself, through its representations, provides the mathematical formalism of quantum mechanics. Once that point is recognized, quantum mechanics emerges from the principle of genuine fortuitousness combined with the embodiment of spacetime symmetry, without any reference to degrees of freedom of particles or fields. The theory, exclusively concerned with probability distributions of genuinely fortuitous clicks, thus differs from previous physical theories in that it does not deal with objects to be measured—which eliminates the issue of a quantum world.

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Aage Bohr
University of Copenhagen
Ben R. Mottelson
(mottelson@nordita.dk)
Nordita
Ole Ulfbeck
University of Copenhagen
Copenhagen, Denmark

David Mermin reported that nobody seems to know what Niels Bohr really said—or meant—or what the Copenhagen interpretation really is. I find that amusing. It appears typical for the confusion arising (necessarily?) from attempts to give Bohr's ingenious pragmatism a consistent meaning.

Could it be that three generations of physicists learned, accepted, and taught an ill-defined quantum theory, and that Einstein's and Schrödinger's reservations were justified—even though those two great men were not yet ready to accept a nonlocal (entangled) reality, as it is described by a general wave function?

H. Dieter Zeh
(zeh@urz.uni-heidelberg.de)
University of Heidelberg
Heidelberg, Germany

Although I was present at a talk David Mermin gave at MIT in the 1980s, I do not recall the exchange with Victor Weisskopf over the quote from Aage Petersen. I do recall that Weisskopf was sitting in the front row of the audience. After the talk, he said something to the effect that Bell's theorem is not so surprising, since it only says that quantum mechanics is inconsistent with a local hidden variable theory and that quantum mechanics is intrinsically nonlocal. Much of what people consider the weirdness or paradoxical nature of quantum mechanics, he said, was really due to its nonlocality; people thought that it ought to be local.

What I remember most, however, is not Weisskopf's comment, but a story told by Stephan Berko, my freshman physics professor in 1966–67, who was also in the audience at that talk. After listening to the rather inconclusive discussion among Mermin, Weisskopf, and others, Berko recalled something that Bohr said to him—in fact, the only thing Bohr ever said to him directly. Berko had been visiting the Institute for Theoretical Physics in Copenhagen in 1958 and attended a holiday party, which featured a magic show. After watching some particularly baffling magic tricks, Bohr turned to him and said, "It's all done with smoke and mirrors!"

Michael Gerver
(mjgerver@aol.com)
Fenster & Co Intellectual Property Ltd
Petach Tikvah, Israel

An Early Route to MHV Tree Amplitudes

In the perturbative expansion of a gauge theory, large numbers of Feynman amplitudes combine to produce mathematically simple (and elegant) expressions. So many people had long suspected that deeper symmetry structures were involved, but those structures remained tantalizingly beyond reach until recently. The Search and Discovery story in the July 2004 issue of PHYSICS TODAY (page 19) gives a lucid and detailed explanation of the evolving understanding of symmetry structures that underlie Feynman amplitudes. Identification of the connection between the maximally helicity-violating (MHV) amplitudes for the $N = 4$ super Yang–Mills theory and supertwistor space was a crucial ingredient in the recent developments.

I would like to share the reasoning that led me, some years ago, to make an early proposal,[1] which unfortunately was not mentioned in the PHYSICS TODAY story. I noticed that the Parke–Taylor formula for the MHV amplitudes involved the inverse of scalar products of spinor momenta that could be related to free fermion propagators (or current correlations of a Wess-Zumino-Witten theory) on the complex projective space CP^1. The space arises naturally (as the fiber) in twistor space. Earlier, Edward Witten had observed that the constraints defining the $N = 4$ super Yang–Mills theory could be nicely interpreted in supertwistor space.[2] Putting these observations together, I wrote a formula for MHV amplitudes in $N = 4$ Yang–Mills theory in twistor language. Conformal symmetry plays an important role. Witten's recent work is more comprehensive, generalizing this complicated series of relationships to string theory and non-MHV amplitudes, and leading to many beautiful results that, for the special case of MHV amplitudes, are identical to mine.

The work I've just described may be useful for practical calculations; but beyond that use, I hope there will emerge a new organizational principle for perturbation theory other than expansion in terms of Feynman amplitudes.

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