EDITOR'S ENDNOTES

David Marcus of Somerville, Massachussetts, writes:

> The article "Bell's Theorem and the Demise of Local Reality" by Stephen McAdam in the November 2003 issue of the Monthly misrepresents the views and contributions of Einstein, Bell, and Bohm to quantum mechanics. Let me attempt to clarify what they did.
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> In orthodox quantum mechanics, the wave function is all you have and the wave function collapses when you take a measurement. This led Schrödinger to give his example of the cat in the box that is both alive and dead until you open the box to look at it. Besides the problem of what constitutes a "measurement," there is the question of why the world seems to be composed of stuff (i.e., particles), when all there really is is the wave function.
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> In 1935, Einstein, Podolsky, and Rosen showed that if locality is true, then the wave function is not a complete description of reality. To do this, they analyzed

an experiment with features similar to that described in McAdam's article, but used the position of two particles rather than the polarization of photons. Unfortunately, they made their example more clever than it needed to be: Assuming locality, a particle had both a well-defined position and momentum. This obscured their main point by making it seem their example violated Heisenberg's uncertainty principle. See [**6**, pp. 139–144] for a discussion.

Bohr's reply to the Einstein-Podolsky-Rosen paper was based on his notion of "complementarity." It has become quantum orthodoxy. Trying to make sense of these issues along the lines laid out by Bohr produces the muddle of quantum philosophy and such statements as McAdam's, "... the momentum of a particle does not exist until something happens to cause its momentum to exist. That something might well be a human experiment designed to measure the particle's momentum."

In 1952, Bohm developed his theory. To the wave function and Schrödinger's equation, he added particles and particle positions. Each particle has a position, and the motion of the particles is governed by a law that involves the wave function. (In 1930, de Broglie made a start along similar lines, but de Broglie dropped the idea to become a supporter of Bohr's views.) Bohm's theory solves the measurement problem and disposes of all the philosophical baggage required by Bohr's approach. The "hidden variables" in Bohm's theory are simply the positions of the particles.

Despite this, Bohm's theory met with little enthusiasm. Bohr's followers didn't see the need. Einstein and those who thought like him were looking for a local theory. Einstein thought that nature was local (as Special Relativity seems to require). At the time that Bohm developed his theory, there was no experimental or theoretical reason to think a local theory was impossible.

In 1964, Bell published his inequality. McAdam states that the hypotheses for Bell's inequality are, "local hidden variables." This not true (or at least very misleading, depending on what you mean by "hidden variables"). The only assumption for Bell's inequality is locality. The fact that the particles must have certain properties ("hidden variables") is a deduction from the observed correlations and locality. See [**2**, chap. 16].

Since experiments show that Bell's inequality is violated, we are forced to drop locality. This removes Einstein's reason for not liking Bohm's theory and explains why Bell liked Bohm's theory. The support for Bohm's work in the physics community seems to be growing.

For those interested in this subject, [**2**] is must reading. Bell's understanding is very deep and his writing exceptionally clear. The other references listed are all worthwhile.

REFERENCES

1. D. Z. Albert, *Quantum Mechanics and Experience*, Harvard University Press, Cambridge, 1992.
2. J. S. Bell, *Speakable and Unspeakable in Quantum Mechanics*, Cambridge University Press, Cambridge, 1987.
3. Bohmian Mechanics, Stanford Encyclopedia of Philosophy, http://plato.stanford.edu/entries/qm-bohm
4. Email correspondence between Sheldon Goldstein and Steven Weinberg on Bohmian mechanics, http://www.mathematik.uni-muenchen.de/~bohmmech/BohmHome/weingold.htm
5. S. Golstein's home page and articles posted there, http://math.rutgers.edu/~oldstein
6. T. Maudlin, *Quantum Non-Locality and Relativity: Metaphysical Intimations of Modern Physics*, 2nd ed., Blackwell Publishers, Malden, MA, 2002.