EINSTEIN'S CHALLENGE TO BOHR

The Einstein/Podolsky/Rosen (EPR) challenge to Bohr took the following form: Imagine that a particle at rest decays into two identical particles, A and B. According to the law of conservation of momentum, A and B will shoot off in opposite directions with the same speed. This means that their positions are always related: If we measure the distance A has traveled, we know the distance B has traveled. Similarly, if we measure the momentum of particle A, we know the momentum of particle B. Now let's suppose we measure the momentum of A after A and B have traveled far enough that no influence, signaling, or connection could occur between them, even if such signaling occurred at the speed of light. In this case, once we know the momentum of A, not only do we also know the momentum of B, but we know, in addition, that measuring the momentum of A could not have had any influence on B: This is because no effect could have passed from A to B, given the distance, unless that effect had traveled faster than the speed of light—which, according to special relativity, is not possible.

In the same manner, once we know the *position* of A (because of the distance it has traveled), we also know the position of B, and, because of the distance between them, we know that our measurement of A could not have influenced B. Again, this is because the effects of that measurement would have had to travel faster than the speed of light in order to do so—and according to special relativity, that is not possible.[1]

By such indirect means of measurement, EPR claims that we are able to determine the exact position and momentum of small particles after all—despite Bohr's denial of

[1] Andrew Whitaker emphasizes that in order to make its argument, the EPR paper did not actually require discussion of the measurement of two properties at all. See M. A. B. Whitaker, "The EPR Paper and Bohr's Response: A Re-Assessment, *Foundations of Physics* 34, no. 9 (2004): 1305–40, and Andrew Whitaker, *Einstein, Bohr and the Quantum Dilemma: From Quantum Theory to Quantum Information,* 2d ed. (Cambridge: Cambridge University Press, 2006), 225–28.

this—and furthermore, that interaction between the two particles cannot be used to explain any correlations observed between them, because interaction would not be possible at that distance.

EPR characterized the general difficulty with Bohr's interpretation as a lack of "completeness." According to this criterion, "every element of the physical reality must have a counterpart in the physical theory,"[2] and the question was whether quantum mechanics, in the orthodox interpretation, accounted for every element of physical reality, or whether it overlooked important variables. Understanding what Einstein means by this may require some subtlety, however. Arthur Fine argues, for example, that in Einstein's view—despite locutions like "physical reality"—it is not that particles with such fixed properties must *literally* exist, but only that any theory that can qualify as complete and empirically adequate must *say* they exist.

This claim imputes to Einstein a distinction between claims about theories (which, though definite, are ultimately provisional and fundamentally provide no more than a coherent set of rules for modeling reality) and claims about reality itself (a much more ambitious, metaphysical task).[3] This distinction locates the difference between Einstein and Bohr at the level of theory (What must a complete and empirically adequate theory say about the world?) rather than at the level of metaphysics (What *is* the ultimate truth about the world?), where the difference is more often located by commentators.

There exists ambiguity in framing the debate, however, because, when writing from a physicist's frame of mind, it is natural for Einstein to speak of theories as if their

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[2] A. Einstein, B. Podolsky and N. Rosen, "Can Quantum-Mechanical Description of Physical Reality be Considered Complete?" *Physical Review* 47 (1935): 777; available at http://www.drchinese.com/David/EPR.pdf.

[3] See Arthur Fine, *The Shaky Game: Einstein, Realism, and the Quantum Theory* (Chicago: University of Chicago Press, 1986), esp. 86–111.

claims are literal, while—when explicitly addressing the *philosophical* issues—he emphasizes that such claims are not actually literal and that the only real question is whether the theory of which such claims are a part is itself a coherent and empirically adequate explanation. In any case, even if we exclude altogether any consideration of metaphysical claims, at the level of theory alone the difference between Einstein and Bohr is important and fundamental.