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Mermin's Suggestion and the Nature of Bohr's Action-at-a-Distance Influence *

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Abstract

Mermin suggests comparing my recent proof of quantum nonlocality to Bohr's reply to Einstein, Podolsky, and Rosen. Doing so leads naturally to the insight that the nonlocal influence deduced from the analysis of the Hardy experiment is the same as the nonlocal influence deduced by Bohr, and used by him to block the application of the criterion of physical reality proposed by Einstein, Podolsky, and Rosen. However, the greater sophistication of the Hardy experiment, as contrasted to the experiment considered by Bohr and the three authors, exposes more clearly than before the nature of this influence, and thereby strengthens Bohr's position.

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Mermin's article[1] fingers a key point. I had taken an even-handed approach, and made no attempt to single out which of my explicitly stated assumptions fails. At least one of them must be invalid, since their conjunction leads to a logical contradiction[2]. Mermin argues that LOC2 fails.

Mermin then suggests linking the putative failure of LOC2 to Bohr's reply[3] to the paper of Einstein, Podolsky, and Rosen (EPR)[4]. That is an excellent idea. The meaning and validity of Bohr's reply has been much debated. Karl Popper[5] claims that Einstein, not Bohr, won that famous battle. John Bell[6] likewise has questioned the rationality of Bohr's argument. Linking Bohr's argument to the presumed failure of LOC2 turns out to be indeed illuminating: it supplies the very element that critics of that argument had deemed missing.

I reject Mermin's other suggestion that there as a 'hidden gap' or 'essential ambiguity' in my argument: the assumption LOC2 in question, is explicitly stated and technically unambiguous. The pertinent question is rather what its failure would mean: in what sense, if any, would its violation entail some sort of faster-than-light influence. I answer that key question now.

The logical form of LOC2 is this:

We have proved (Mermin grants), under the condition that L2 is performed in the left-hand region, the truth of the follow statement:

(S): If performing R2 were to give +, then performing R1, instead, must give -.

Statement (S) was proved, as the initial proviso indicates, under the condition that L2 was performed in the faraway space-time region L, which can be considered to lie later in time than the space-time region R within which the possible experiments R1 and R2 and their possible results are confined.

That is, the direct proof of (S) would fail if L1 were to be performed at the later time rather than L2.

But LOC2 claims that statement (S), which refers explicitly only to possible experiments and results confined to R, cannot be true if someone at a later time freely chooses to do one thing but false if that person freely chooses to do something else instead.

Mermin claims that I 'overlooked' essentially the fact that the direct proof of (S) fails if L2 is not performed. Exactly the opposite is true: I introduced

LOC2 precisely to get around that problem. The pertinent issue is not whether the direct proof continues to hold under condition L1—it certainly does not—: it is rather whether a nontrivial dependence of the truth of (S) upon a future free choice means that there is some sort of backward-in-time influence, even though the statement (S) is a counterfactual assertion.

The point, as I see it, is that if L2 is chosen, then it is provably true that in any instance for which R2 gives +, R1 would have given -: e.g., every time a 'color' measurement gives "red", not "green", a 'firmness' measurement would necessarily have given "hard", not "soft". Although the proof of this connection depends on the later free choice being L2, the conclusion is a connection between two earlier properties: redness entails hardness. Even though both properties cannot be simultaneously determined empirically, there is an invariable relationship between what happens under two alternative conditions. This means that Nature's choices under these two alternative earlier conditions must be correlated in a certain way, provided L2 is freely chosen at the later time, but—if LOC2 is violated—cannot correlated in this way if the later free choice is L1. But this means that if LOC2 were to be violated then there must be some sort of backward-in-time influence: Nature's choices under alternative possible earlier experimental conditions necessarily must be constrained in one way if the later free choice is L2, but in some different way if the later free choice is L1.

I formulated my locality condition in terms of the dependence of the truth of statements pertaining to 'possible measurements and their possible observable outcomes that are all localized in a space-time region that lies earlier than some time T': the locality condition was that the truth of such statements cannot depend upon free choices made by experimenters after time T.

Mermin asserts that the failure of this locality condition "does not mean, however, that a choice made in the future (whether to perform L1 or L2 on the the left) can influence events in the present." However, the term "influence events" contains an essential ambiguity. What certainly is true is that is the faster-that-light influence entailed by a failure of LOC2 is not of the simplest kind: it involves not just differences of what happens in the one actually occurring experimental situation, under different faraway conditions, but rather differences in the contraints imposed upon Nature's earlier selections under the different conditions that we are free to set up faraway and later.

This situation, in which there is a subtle action-at-a-distance influence, but no simple direct one, certainly brings to mind Bohr's basic claim in his reply to EPR:

[T]here is... no question of a mechanical disturbance of the system under investigation...[but] there is essentially the question of an influence on the very conditions which define the possible types of predictions regarding the future behavior of the system.

In both cases there is a denial of any (proof of a) direct mechanical disturbance of events in the single actually occurring situation, but an affirmation of the existence of an influence of some kind.

So I follow Mermin's suggestion that an examination of this similarity between what Bohr claims and what a failure of LOC2 entails "might offer some illumination to those have difficulty understanding Bohr's reply to Einstein, Podolsky, and Rosen (EPR)".

The meaning of Bohr's argument has been much debated. Mermin cites Plotnitsky's book[7] for a "thoughtful critique of Bell's statements about Bohr's views". Plotnitsky roundly condemns Bell as completely failing to understand Bohr. Bell himself admits to not understanding Bohr's argument, but with the implication that Bohr's argument does not make sense. Plotnitsky cites some key phrases of Bohr that Bell did not mention, namely "the wording of the above mentioned criterion of physical reality proposed by Einstein, Podolsky, and Rosen contains an ambiguity as regards the meaning of the expression 'without in any way disturbing a system' ", and [at the end of a passage cited above] "these conditions constitute an inherent element of any phenomena to which the term 'physical reality' can be applied." Plotnitsky suggests that the reason that Bell does not understand Bohr's argument is perhaps that he refuses to read the full argument that gives meaning to these important phrases. I am confident that Bell, a thorough scientist, did examine Bohr's full argument carefully before publically criticizing it.

What Bohr's full argument shows is that if we take the point of view that the quantum formalism is a procedure for making, on the basis of knowledge that we acquire by performing possible measurements, predictions about the outcomes of our later possible observations, then performing one of the earlier possible measurements may exclude the possibility of performing an alternative possible one. Applied to the particular example that EPR considered, this consideration was shown to entail that if one sets up the system so that $q_1 + q_2$ and $p_1 - p_2$ are both well defined, as EPR specify, then one can measure either q_1 or p_1, but not both, and hence become able to predict either q_2 or p_2 but not both. Thus, from Bohr's perspective, in which the meaning of "physical reality" is tied to our acquiring the knowledge needed to make predictions about it, measuring q_1 does disturb the other system because it produces "an influence on the very conditions which define the possible types of predictions regarding future behavior of the [other] system." Thus if we measure q_1 then we cannot make a prediction about p_2.

By this argument Bohr disputes the key EPR claim that performing a measurement on one of two correlated—but currently non-interacting—systems does not "disturb" the other.

So the point of Bohr's argument is to assert that within his knowledge-based and prediction-oriented Copenhagen framework there IS an action-at-a-distance influence, and the existence of this action-at-a-distance influence blocks the EPR (implicit) claim that there is none, thereby blocking application of the EPR criterion of reality

How does Bohr's claim that there IS an important action-at-distance influence relate to my similar claim?

The EPR-Bohr debate centered on the EPR criterion for physical reality:

"If, without in any way disturbing a system, we can predict with certainty the value of a physical quantity then there exists an element of physical reality corresponding to that physical quantity".

The central question in judging the adequacy of Bohr's reply is whether the faster-than-light influence that he claims exists, within his knowledge-based framework of thinking, can be both sufficiently real to block the application of the EPR criterion of physical reality, yet sufficiently unreal to produce no mechanical disturbance. That is the problem that troubled Bell, and probably everyone else who is troubled by Bohr's argument

A main objective of my work was to rid the argument of these "reality" questions that have led into a philosophical quadmire of interminable disputes.

In Mermin's section "What's wrong?" he says that the step from line 5 to line 6 of my proof is wrong. But the failure of this step is exactly the claim that LOC2, as it is applied, is not valid. That is just what I am trying to show, or in any case is sufficient. The crucial question, however, is whether such a failure of LOC2 entails some sort of faster-than-light influence. I have given, above, a direct argument that it does.

Mermin gets involved in questions of definitions and meanings, as did Bohr. But Bohr had to involve himself with such matters because he was confronted by a characterization of "physical reality" that was basically alien to what arises from his own knowledge-based approach. Hence he was forced, in effect, to redefine this key term to bring it into line with his own philosophy. My approach is designed to circumvent these definitional issues.

Specifically, Mermin questions whether the fact that statement (S) refers explicitly only to possible measurement and possible results confined to the right-hand region R really justifies making the step from line 5 to line 6? His point is that the original proof of (S) depends on the fact that L2 is performed in region L, and so he would like therefore simply to stick with that result and hence allow the truth of (S) to depend on the future choice between L1 and L2. But I claim that my argument given above shows that denying the validity of LOC2 in this way does entail some sort of backward-in-time influence of the later free choice on Nature's earlier selection process: certain rigid connections between what these earlier selections can be under alternative possible conditions in region R must exist if L2 is performed in L, but must fail to hold if L1 is performed there.

This result pertaining to LOC2, carried over to the EPR-Bohr case, would mean that in that case connections between Nature's choices of the outcomes of measuring q_2 or alternatively p_2 cannot be assumed not to depend upon whether q_1 or p_1 is measured. But this means that one cannot pass from the fact that one can measure either q_1 or p_1, and hence determine either q_2 or p_2, to the conclusion that both results are simultaneously well defined: one cannot assume that all connections between outcomes of alternative possible measurments that could be performed in one spacetime region are independent of what someone will choose to do faraway and later. This result, which is what the analysis of the Hardy experiment shows, gives solid support to Bohr's position as opposed to EPR. So I think that the faster-than-light influence that I have established is basically in line with Bohr's reply to EPR, and indeed that the faster-than-light influence that Bohr deduced from an analysis of possible knowledge-based predictions is essentially the same as the one that I deduced from an analysis of the Hardy experiment. However, the sophistication of the Hardy experiment, in comparison to the simple EPR experiment, allows the nature of this influence to be exposed now more clearly than before. This identification of my faster-than-light influence with Bohr's entails that this faster-than-light influence is, as Bohr claimed but critics doubted, logically sufficienty to block the application of the EPR criterion of physical reality.

I have adopted, throughout, the straight-forward meanings of logical propositions, and not tried to evaded drawing the anti-intuitive conclusions that logic demands by adopting some rule that capriciously asserts well-formed propositions to be "meaningless", rather than merely true or false, and provable or unprovable, when they have a perfectly clear meaning. Nor do I think that Bohr's policy was one of the evasion of logic. Quite the opposite! He did not seek to denigrate or deny an action-at-a-distance influence that logic called for by curtailing the power of logic. Rather he pushed logic to the limit to show that rational analysis demanded an action-at-a-distance influence, and did not shirk from accepting that conclusion even though it flew in the face of common sense classical intuition. He used the 'essential ambiguity' that he identified, which concerned what he viewed as an overly restrictive view of the meaning of "without in any way disturbing a system", to enlarge the meaning of "disturb", not to curtail its meaning by arbitrarily limiting the scope of logical reasoning.

The major weakness in Bohr's position, however, was that the action at a distance whose existence he claimed seemed, to many critics, to be too unphysical to really do the job. This action seemed to exist only in some nebulous realm, that might be 'defined' to be physical reality, but that seems too abstract and ghostly to really impact on physical reality. Thus the Hardy-based analysis fortifies Bohr's position at its weakest point, by allowing the needed action at a distance to be deduced more directly from the unquestioned structure of the predictions of the theory than from a debatable philosophical commitment concerning the nature of the scientific endeavour, and a radical re-interpretation of the meaning of physical reality.

References

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